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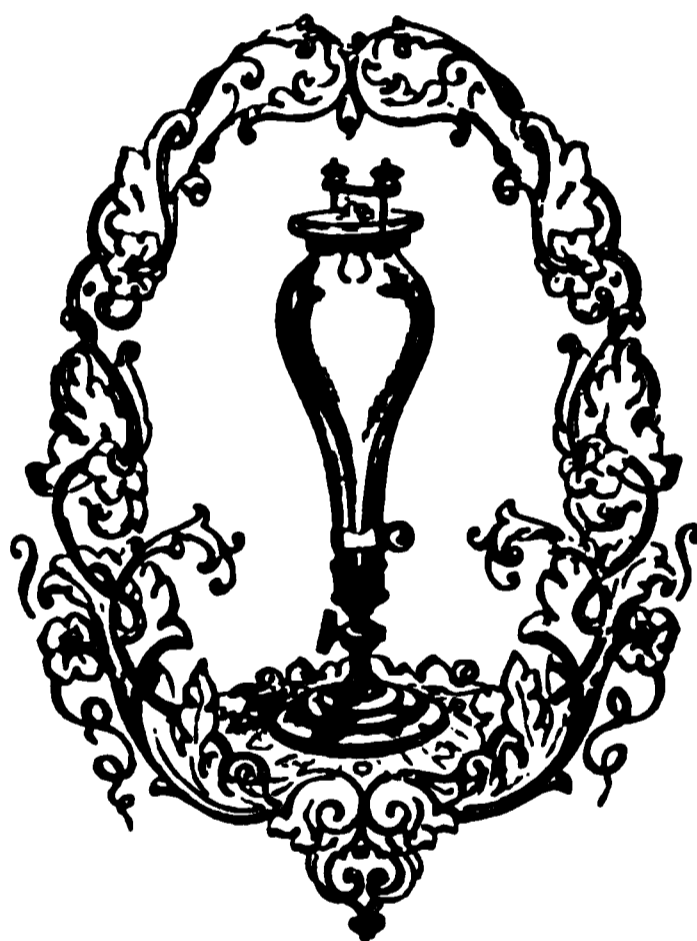
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CHEMICAL AND PHYSICAL

GEOLOGY.

BY

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Specimens of mica from the following localities were analysed by him, and found to contain fluorine, the amount decreasing in the order they are named:

Grey Mica.

Brodbo.
Zinnwald.
Altenberg.
Mursinsk.
Siberia.

Golden Yellow Mica.

Kimito.
Börstils Säcken (Sweden).
Utön.
Massachusetts.
Russia.
Pargas.
Sola.

Rose observed that the amount of fluorine in mica is greater or less in proportion to the amount of iron present, and hence considers it probable that the fluorine is combined with iron. It is, however, more probable that the fluorine is combined with alkaline metals in mica, and chiefly with potassium. Fluoride of silicium cannot be present in combination with metals, because the mica experiences only a very slight diminution of weight when ignited. It is, moreover, impossible for fluo-silicate of sodium to exist with carbonate of soda in solution in water; these salts would be mutually converted into fluoride of sodium and silica, unless indeed they were dissolved in such minute quantity as not to react upon each other.

In amblygonite, fluorine is associated with phosphoric acid, aluminum, lithium, and sodium, and it must be regarded as combined with one or other of these metals. Rammelsberg proposes to make a partition of the fluorine among the metals according to their equivalents.

The fluorine in yttrocerite is undoubtedly combined with calcium, cerium, and yttrium.

When the number of metals in a mineral is great, there is more difficulty in conjecturing with which the fluorine is combined.

Thus pyrochlore contains no less than nine metals, and leucophane five, and among them, the calcium is more than equivalent to the fluorine, which probably exists as fluoride of calcium in both minerals. So likewise the fluorine in parisite is probably combined with calcium, and the amount of calcium in œschynite, in the varieties of hornblende, in wernerite and apatite, is sufficiently large to admit of the assumption that the fluorine in these minerals exists as fluoride of calcium. Berzelius was of opinion that the fluorine in wavellite is probably combined with aluminum.

The researches of Rammelsberg would appear to show that the amount of fluorine in apophyllite is not constant. With regard to the state of combination of fluorine in minerals, he is of opinion that the fluo-silicate obtained in analysis can scarcely be a constituent of the minerals, but is rather a product.

Apophyllite is a hydrated mineral, occurring in drusic cavities and clefts, and both these circumstances indicate its aqueous origin by deposition from water containing silicates of potash and lime. The presence of fluorides in water, although in exceeding minute quantity, is sufficiently frequent to account for their presence in apophyllite. If the fluoride in such an instance were fluoride of potassium, fluoride of calcium and silicate of potash would be precipitated, owing to the presence of silicate of lime.

Berzelius found that the apophyllite of Utö contains 1.54 per cent of fluorine, which if combined with potassium, would yield 3.88 per cent. of potash, while the analysis gave 5.27 per cent. of potash. Rammelsberg found in the apophyllite of Andreasberg, 1.28 per cent. of fluorine, equivalent to 3.23 of potash, while the analysis gave 4.9 per cent. potash. So that, in both instances, the analysis gives more potash than is equivalent to the fluorine present, and, consequently, part of the potassium must be combined with silica; and this must be the case to a still greater extent when the fluorine does not amount to more than a very small fraction of the potassium in the mineral. But if silicate of lime was essential for the formation of apophyllite, the fluorine this mineral contains could not have performed any other than a subordinate function. In every case however, the fluorine in these minerals must be regarded as combined with calcium; because fluoride of potassium and silicate of lime cannot come in contact without experiencing mutual decomposition.

Cryolite and chiolite are simply compounds of the fluorides of sodium and aluminium.

There are no data which can serve as a means of deciding what is the state of combination of the fluorine present in carpholite and cronstedite, as well as in all minerals which contain only minute traces of this element.

The three zeolites, apophyllite, carpholite, and cronstedite, furnish striking examples of the formation of fluoritic minerals by infiltration.

So far as our knowledge extends, fluorine occurs in minerals only in combination with the alkaline metals, calcium, magnesium, aluminum, cerium, and yttrium. The presence in parisite of so

large an amount as 23·5 per cent. of carbonic acid—certainly not an original constituent of this mineral—shows that minerals containing fluorine undergo decomposition. In like manner, the basic fluoride of cerium with 4·95 per cent. of water may be regarded as a decomposition-product of the neutral fluoride; and the pyrochlore of Brevig, definitely characterized by containing uranium, and water as an essential constituent, is a further instance of such alteration.*

Fahlunite and gigantolite contain merely traces of fluorine; and the large amount of water in these minerals favours the opinion that the fluorine has been introduced into their substance together with the water.

Haidinger† regards corderite as the initial member of a transition series of minerals ending with mica. Fahlunite, gigantolite, chlorophyllite, bonsdorffite, pinite, etc., he considers to be pseudomorphous derivatives of corderite. Now fluorine has never been detected in corderite, and it is remarkable that fluorine is present only in the immediate products of the alteration of this mineral, and not in those which are more remote, particularly pinite, while it again appears in mica.‡

The amount of chlorine in apatite varies much. In that of Ehrenfriedersdorf and of Gotthardt, it is almost inappreciable, while on the other hand fluorine is most abundant. G. Rose§ has shown that apatite consists of 3 equivalents of basic phosphate of lime, and either 1 equivalent of chloride of calcium, or 1 equivalent of fluoride of calcium. It may likewise consist of mixtures of these two compounds.

<i>Chlorapatite.</i>		<i>Fluorapatite.</i>		<i>Apatite of Snarum.</i>	
Chloride of calcium	10·62	Fluoride of calcium....	7·69	Chlorapatite	40·3
Phosphate of lime	89·38	Phosphate of lime	92·31	Fluorapatite	59·7
	<hr/> 100·00		<hr/> 100·00		<hr/> 100·00

* Wöhler—Pogg. Annal. xlviii. 90—leaves it undecided whether the pyrochlore of Brevig is identical with that from Friedrichswärn, or whether it constitutes a third variety. In many instances the composition and crystalline form appear to indicate a general identity, and it is very probable that the differences observed are owing to alteration which is so frequently induced by the assimilation of water together with substances held in solution by it.

† Abhandlungen der Böhmisches Gesellschaft der Wissenschaften, 5^{te} Folge. Bd. iv.

‡ Further and more precise analyses require to be made, in order to clear up this point decisively.

§ Poggendorff's Annalen. ix. 195. See likewise Rammelsberg's Handwörterbuch, Zweites Supplement, p. 16.

Fluor-spar is the most abundant* and frequent of the native compounds of fluorine. It occurs in drusy cavities in amygdaloid rocks, in veins and dykes, in granite, gneiss, mica slate, porphyry, diorite, dioritic porphyry, and granular limestone.

It frequently constitutes a large part of the contents of metalliferous lodes, and of veins in clay-slate; it likewise occurs in drusy cavities in variegated sandstone, in mountain limestone, calcaire grossier, in sandstone breccia, and in gypsum containing sulphur.

The occurrence of fluor-spar in these situations, its association with such minerals as brown hematite and with substances† composed of carbon, hydrogen, and oxygen, that are not only produced, but likewise decomposed, under the influence of heat, and its occurrence as a petrifying substance, are all indicative of its formation in the wet way.

The fact of its occurrence in erupted masses at Vesuvius, intimately blended with idocrase, hornblende, augite, mica, nepheline, and sodalite might seem to favour the opinion that it has been formed by igneous fusion; but since the lava, on account of its porous character, is easily permeated by water, and since the fluor-spar crystals, which are very minute, occur only in the older erupted masses, there is more probability that the fluoride of calcium in this case is a product of the decomposition of fluoritic minerals existing in those masses.

The occurrence of fluor-spar in drusy cavities and in dykes of crystalline rocks, containing mica and hornblende, is unmistakeably connected with the presence of fluorine in these minerals. This is rendered more strikingly obvious by the circumstance that fluor-spar is never found in the drusy cavities of augitic rocks (basalt) or of trachyte, and no trace of fluorine has ever been detected in augite. It is indeed stated that fluor-spar, associated

* The most extensive fluor-spar lode that is known, is stated by Breithaupt to be in the zechstein on the "Alten Liebenstein" (Meiningen). *Paragenesis der Mineralien*, p. 200.—Cubes of fluor-spar more than a foot in diameter have recently been found in the limestone on the shore of the Missouloungua Lake (New York).

† Schaffhäutl.—*Ann. der Chemie und Pharmacie*, lxvi, 344—states that the violet-coloured fluor-spar of Welsendorf, in the Oberfalsz, contains 0.00584 per cent. hydrogen, 0.0365 per cent. carbon, and 0.02073 per cent. nitrogen. The presence of these substances affords reason for the inference that organic substances were deposited by the water, together with the fluoride of calcium. Probably the disagreeable odour evolved by this and some other kinds of fluor-spar, when struck or rubbed, is owing to the presence of organic substance, and the diversity of colours presented by this mineral may also depend upon the same circumstance.

with quartz and calc-spar, occur in veins traversing dolerite,* at Bolanos (Mexico).

The existence of pseudomorphous quartz, chalcedony, hornstone, hematite, brown hematite, iron pyrites, white iron pyrites, psilomelane, steinmark, chlorite, siliceous oxide of zinc, calamine, carbonate of lead, bitter spar, and calc-spar, after fluor-spar, as well as the presence of fluoride of calcium in water, furnish evidence of its actual removal by water.† Some of the substances above enumerated are less soluble than fluoride of calcium, and this circumstance is consistent with the general rule that pseudomorphous substances are less soluble than the substances whose form they bear. The last four, especially the carbonates of zinc, magnesia, and lime, are undoubtedly more soluble than fluoride of calcium, and this may admit of the conjecture that the fluoride of calcium was not directly replaced by them.‡

* The chemical nature of the acid evolved by the action of heat upon hedenbergite, dark green augite, and dark red malakolite, has not yet been ascertained.

† W. Phillips—Mineralogy 1823, p. 7—describes a mineral in the collection of the Philosophical Society at Truro, consisting of hollow cubic crystals, which are made up of small crystals of quartz, and are nearly filled with water.

‡ Von Dechen — Archiv. xxi, 551 — observes, in opposition to the view I have taken of the formation of fluor-spar, that although it may serve as an explanation of the occurrence of minute quantities of this mineral in dykes, still it cannot be applied to the great masses of fluor-spar, occurring in the grauwacke of the Harz, and at the south-west border of the Thuringian forest.

The only other views that can be adopted respecting the origin of these masses of fluor-spar are, that they were protruded, in a state of igneous fusion, from the interior of the earth into large fissures, or that they were produced by the decomposition of carbonate of lime by vapour of hydrofluoric acid. The supporters of the Plutonic Theory actually suppose that they were produced by one or other of these processes, notwithstanding such an assumption as the former is inconsistent with the known behaviour of fluoride of calcium as a flux in metallurgical operations. If melted fluoride of calcium had been forced up through a fissure, in grauwacke for instance, there is every reason for believing that the rock at the sides of the fissure would have been melted and mixed with the fluoride, thus forming a kind of saalband, between the fluor-spar occupying the middle of the dyke, and the rocks traversed by it. Nothing of this kind, however, has been observed in the localities above referred to; and the opinion that fluoride of calcium has, in any instance, been introduced in a melted state into fissures must, therefore, be regarded as altogether untenable.

With regard to the second view, even granting that hydrofluoric acid may be generated in the interior of the earth, it could only be supposed to act upon rocks situated in the immediate neighbourhood of its evolution, and not upon rocks situated at a distance, to reach which it would be necessary for the vapour to traverse fissures in such rocks as grauwacke, upon which it acts chemically, producing fluoride of silicium.

It may indeed be argued that the evolution of hydrofluoric acid was probably so copious and rapid that it was only partially converted into fluoride of silicium by reaction with the silica of the rocks through which it was conveyed; but in this case the fluoride of silicium would have been decomposed on coming in

Berzelius was the first to detect fluoride of calcium in the Carlsbad water and in the deposits formed by it. Its presence was also pointed out in other Bohemian mineral water, and since that time it has been found in the water of several springs in other countries.

The detection of fluorine in ordinary water is very interesting. Middleton* found fluorine in greater or less amount in the following substances:—

1. The deposit in a chloride of lime vat.
2. The deposit in a water-pipe of a coal-mine.
3. A stalactitic deposit from old red sandstone contained about 8 per cent. of fluoride of calcium.
4. A deposit in a wooden pipe for conducting water from a building.
5. Deposit in a kettle used solely for boiling water.
6. Portion of a vein of sulphate of baryta from old red sandstone.
7. Fossilized wood from Egypt consisting of carbonate of lime.
8. Fossilized wood from Egypt, consisting of silica, contained only a trace of fluorine.

It has long been known that fossil bones contain more fluoride of calcium than recent bones. Middleton† found that fluorine is present not only in the bones of mammalia but likewise in those

contact with water at or near the earth's surface, and the silica thus produced would have been found as silicious sinter, partly in the fissures and partly upon the surface. Nothing of this kind, however, is to be seen at the outcrop of the fluoride-spar dykes above referred to.

The supposed action of hydrofluoric acid, rising from the interior of the earth, upon rocks within the range of observation must therefore be entirely rejected.

I have shown, in the German edition, i, 527, to what inconsistencies we are led by assuming that the evolution of hydrofluoric acid can take place in limestone.

With regard to the objections raised by V. Dechen, it may be observed, that the mere magnitude of masses is not a sufficient reason for supposing that they have not been produced in the same manner as smaller masses of the same kind. If it can be shown that the smallest veins of quartz in grauwacke have been formed in the wet way, and of this there can scarcely be any doubt, the opinion that the largest quartz dyke has been formed in the same manner does not involve any greater difficulty. The only difference is, that the formation of the larger mass required a greater time.

* Gilbert's Annal. lxxiv, 135 and 138.

† Edinburgh New Phil. Journ. 1844, p. 285. Daubeny—on the occurrence of fluorine in recent as well as fossil bones—Idem. p. 288—found that fossil bones contain more fluorine than recent bones. He is of opinion that the difference may be only apparent, and dependent upon the perfect destruction of the organic substance in fossil bones, since the difficulty in separating fluorine is greater in proportion to the amount of organic substance present.

of birds and reptiles, as well as in the shells of mollusca.* Its presence in the shells of these animals he regards as a decisive proof that fluorine is as widely distributed as water itself.

Experiments have since been made by Dr. G. Wilson.† He found that when carbonic acid is passed into water, mixed with finely powdered fluor-spar, so much is dissolved that the liquid gives a precipitate with oxalate of ammonia, and by evaporation yields a residue which evolves hydro-fluoric acid on the addition of sulphuric acid. The liquid remained clear after all the carbonic acid had been expelled by heat; and he therefore inferred, that fluoride of calcium is really soluble in water. He estimates the solubility at 1 part in 26923 ‡ parts of cold water and less hot water.

The water solution of fluoride of calcium gives, with baryta salts, a precipitate which requires a large quantity of hydrochloric or nitric acid for solution, and hence arises a difficulty in distinguishing between fluorides and sulphates in solution; so that in the analysis of mineral water the presence of fluorine may be overlooked. Moreover, the ordinary method of estimating fluorine as fluoride of calcium cannot, on account of the solubility of that substance, yield satisfactory results. It is preferable to estimate fluorine as fluoride of barium, which is much less soluble than fluoride of calcium.

Wilson found fluorine in the water of a spring near Edinburgh; in sea water; and in considerable amount in the mother-liquor from the manufacture of salt, by evaporating the water of the Frith of Forth.

Thus, then, all the four salt radicals, chlorine, bromine, iodine and fluorine are present in sea water. Forchhammer§ found fluoride of calcium in the water of the Baltic.

Berzelius|| concluded, from his experiments, that the solvent of fluoride of calcium in the Carlsbad water is bicarbonate of soda,

* The analysis of fossil bones of various animals—horse, camel, &c.—from the Sewalic hills gave 10·65 to 11·68 per cent. fluoride of calcium. A Greek skull, about 2000 years old, was found to contain 5·04, and the skull of an Egyptian mummy 6·01 per cent of this substance; while on the other hand, a skull from the wreck of the Royal George was found to contain only 1·86 per cent., and a still more recent skull 1·99 per cent. The greater proportion of fluorine in fossil bones can only depend on the circumstance that bones contain more of this substance the longer they have been exposed to infiltration.

† Edinburgh New Phil. Journ. 1846, p. 205.

‡ Ibid. xlix, 230.

§ Ibid. 1850, p. 345.

|| Wilson confirmed Will's detection of fluorine in plants. Following out the observation of Berzelius that it exists in the structure of the kidney, he detected it likewise in blood and milk. The presence of fluorine in these liquids is a further evidence of the wide distribution of this element.

but that the water does not contain fluoride of sodium. He estimated the very small quantity of fluoride of calcium in this water by analysis of the deposits formed round the springs. In most of these deposits the fluorine is combined with calcium; some, however, contain fluo-silicate of sodium.

The carbonate of lime and fluoride of calcium, being retained in solution by carbonic acid, would be precipitated together, as soon as the gas is expelled. On this account, Berzelius considered that these substances are present in the deposit in the same relative proportion as in the water; and thus he estimated that the water contains $\frac{1}{312500}$ fluoride of calcium.* This is much less than the proportion in which Wilson found that fluoride of calcium is dissolved by water, so that there is no occasion for supposing, as Berzelius did, that the solution of this substance in the water of springs is determined by the presence of bicarbonate of soda.

The residue left on evaporating a large quantity of the Carlsbad water does not give any indication of fluorine when treated with sulphuric acid, because there is so much silica present that the fluorine escapes as fluoride of silicium. There is, therefore, an essential difference between the deposits formed by this water and the residue obtained by evaporation: the former contain only the substances held in solution by carbonic acid, while the latter contains all the dissolved substances, and, among others, silica.

The researches of Berzelius also explain why native fluo-silicate of calcium does not occur; for although fluorine and silicium enter into combination so readily, fluoride of calcium and silica may be present together in water without any deposition of fluo-silicate of calcium. Consequently silica dissolved in water may be substituted for fluoride of calcium, as in the case of pseudomorphous siliceous minerals after fluor-spar, and quartz may be deposited upon fluor-spar or fluor-spar upon quartz.

Fluoride of calcium is not decomposed by potash or soda, either in the wet way or by fusion; but it is readily decomposed by fusion with alkaline carbonates. Berthier† states that when fluoride of calcium is melted with carbonate of potash an easily

* According to Gilbert—loc. cit. p. 200—the quantity of sulphate of soda annually produced from the whole of the hot springs of Carlsbad amounts to 20,000,000 of pounds; and taking Berzelius's estimate, that the proportion of this salt to fluoride of calcium is as 258713 : 0·0032, the quantity of fluoride of calcium deposited annually, amounts to 24,700 pounds. If such water were to flow for thousands of years through a fissure, fluor-spar might be deposited in masses as large as those found in dykes.

† *Annal. de Chimie et de Phys.* xxxviii, 246.

fusible compound is produced even when the quantity of the carbonate is not sufficient for the complete decomposition of the fluoride. I have found that the same decomposition takes place in the wet way, not only at the boiling-point but also at the ordinary temperature.* It is, therefore, reasonable to suppose that fluor-spar would, by contact with water containing alkaline carbonates, be converted, even at the ordinary temperature, into carbonate of lime. If the water were insufficient in quantity for the removal of the carbonate of lime thus produced, there can be no difficulty in understanding that the conditions would be highly favorable for the production of pseudomorphous calc-spar. In that case, however, the pseudomorph would be formed by alteration, not by displacement.

The only known instance of pseudomorphous fluor-spar† is that after calc-spar; it occurs in the Teufelsgrund mine at Niedermünsterthal. In this case the respective solubility of carbonate of lime and fluoride of calcium, is in accordance with the general rule already stated.

Although it could not be supposed that alkaline fluorides would decompose bicarbonate of lime, I made an experiment to determine

* English edition, i, 11, No. 7. The fluoride of calcium which remains undecomposed, is dissolved to no inconsiderable amount by hydrochloric acid; but this is owing to a partial decomposition. When fluoride of calcium, prepared by precipitating a solution of a lime-salt by fluoride of potassium, is mixed with hydrochloric acid in a glass vessel, a very marked corrosion of the surface is effected. The solution, which is perfectly clear at first, appears to become turbid in a few days, but when closely examined this is found to be due to the corrosion of the glass.

The solubility of fluoride of calcium in hydrochloric acid must be borne in mind in the examination of water, or any substance in which its presence is conjectured, and as Pearsain remarks—*L'Institut*. 1844, p. 568—the presence of fluorine in water has hitherto escaped the notice of chemists, probably from inattention to this very circumstance. He also states that fluoride of calcium may be obtained in crystals by evaporating a solution in hydrochloric acid.

In one of my experiments, a solution containing $\frac{1}{80}$ carbonate of potash was mixed with $\frac{1}{1000}$ powdered fluor-spar. By mutual decomposition $\frac{1}{84}$ carbonate of lime was formed and entirely dissolved, which is very remarkable, because water saturated with carbonic acid does not dissolve so much carbonate of lime. It must therefore be inferred, either that carbonate of lime is more soluble in the nascent state, or that it forms with fluoride of calcium a double salt which is more soluble. Hence it follows, that the carbonate of lime that would be formed by the contact of fluor-spar with water containing alkaline carbonates would be dissolved; and it also appears probable that many substances which are regarded as insoluble may be dissolved while in the nascent state, and that others which are very sparingly soluble may, while in this state, be dissolved to a much greater extent than when already formed.

† Blum—*Die Pseudomorphosen*, Erster Nachtrag, p. 19.—These displacement pseudomorphs occur also elsewhere. Bournon—*Catalogue de sa Collection*, p. 11—states that in the mountain limestone of Derbyshire entrochites (cyathocrinites) are found, consisting partly of fluor-spar and partly of calc-spar. In Werner's collection

this point. A solution of fluoride of sodium was mixed with a solution of bicarbonate of lime, but not the slightest turbidity was produced even with the aid of heat. A hot solution of bicarbonate of lime and fluoride of potassium likewise exhibited no turbidity on cooling. After such a solution had stood for about six weeks in an open vessel, the carbonate of lime, which had in the meantime been precipitated, did not contain any trace of fluorine.

Fluoride of sodium and silicate of lime are mutually decomposed in solution. When silicate of lime, prepared artificially,* is treated with boiling solution of fluoride of sodium, the liquid immediately acquires a strong alkaline reaction, owing to the formation of silicate of soda. This decomposition takes place, even at the ordinary temperature, when a solution of fluoride of sodium is allowed to remain for sixteen hours in contact with silicate of lime. In the former case, the residue, after being washed, does not evolve hydro-fluoric acid, when mixed with sulphuric acid, but in the latter case it does.

The production of fluoride of calcium by mutual decomposition of silicate of lime and alkaline fluorides at the ordinary

there is a fine column of crinoidea imbedded in crystallized fluor-spar, and Sack observed joints of the columns of *rhodocerinus verus*—Goldf.—that became apparent on breaking a large crystal of fluor-spar. The frequent presence of fluor-spar in limestone and fossil bones would seem to indicate that fluoride of calcium was precipitated from water by the carbonate of lime in the limestone and in the bones. According to Dana—Silliman's Amer. Journ., 1846, II, 88—the fluorides in the coral masses appear to amount to 0.25 per cent., and the phosphates to 0.05 per cent.; hence a coral reef one mile long, half a mile broad, and 100 feet high would contain more than 500 million pounds of these substances. The occurrence of fluor-spar, apatite, and chondrodite in limestones composed of coralline and testaceous remains, is accounted for by the presence, in coral and shells, of fluorides with phosphates, and of silica, which amounts to somewhat less than the fluorides. However, these minerals are certainly not formed, as Dana supposes, by the attraction and accumulation of similar particles. Carbonated water penetrating such masses dissolves carbonate of lime and fluoride of calcium; then, by continued contact with the rock, carbonate of lime is dissolved, and fluoride of calcium deposited in its place. We may safely assume that in this way large cubes of fluoride of calcium would be formed. Dana admits that fluoride of calcium may crystallise from water; according to him, the crystallisation of apatite and chondrodite presupposes the influence of heat, because they occur in granular limestone. He considers that these minerals have been formed under the influence of heat, at the same time that the limestone acquired the granular structure. This is a singular instance of the influence of unfounded hypotheses in leading to inconsistent opinions; for it may be asked, why should not apatite, which is soluble in water, be crystallised in the same manner as the fluoride of calcium occurring in granular limestone? Is fluor-apatite to be regarded as produced under the joint influence of igneous and aqueous action?

Pseudomorphous apatite, after calc-spar, by displacement, has not been met with; but since phosphate of lime is so much less soluble than carbonate of lime, it is not improbable that apatite may be precipitated from a water solution by carbonate of lime, and that the apatite in limestones may be formed in this manner.

* English edition, i, 14, No. 24.

temperature, has an important geological significance, for it shows in what manner fluor-spar may be produced.

The compound silicates are likewise decomposed by fluoride of sodium. When powdered basalt, melaphyr or trachyte, is mixed with a boiling solution of fluoride of sodium, the strong alkaline reaction acquired by the liquid shows that decomposition takes place; but the residue* after being washed and mixed with sulphuric acid, furnishes only obscure indications of fluorine. This probably depends upon the fluorine being for the most part evolved in combination with silicium.†

We have seen that fluorine occurs very frequently in water. Although in sedimentary deposits and in fossil bones, it is found invariably combined with calcium; it does not follow that it exists in this state of combination in water, for when a deposit is formed by water containing silicate of lime and an alkaline fluoride, the fluorine is, according to my observations, deposited as fluoride of calcium; and thus the presence of fluoride of calcium in the deposit formed at Carlsbad is satisfactorily accounted for.

Berzelius could not detect any fluoride of sodium in the Carlsbad water; but it is probable that this is the form in which fluorine is extracted from the rocks: perhaps from the mica of granite. Then if silicate of lime is dissolved at the same time the two salts are mutually decomposed, silicate of soda and fluoride of calcium being formed. The latter is precipitated together with carbonate of lime, and is thus found in the deposit formed round the springs.

Since fluoride of sodium decomposes phosphate of lime,‡ fluor-spar may sometimes be formed in this way. The greater proportion of fluoride of calcium in fossil bones, may, therefore, be a result of the decomposition of phosphate of lime by alkaline fluorides, which are probably often present in the water of springs.

The fluoride of aluminum, obtained by dissolving the hydrated oxide by hydro-fluoric acid and evaporating, appears as a perfectly

* In examining the residue for fluorine, it is requisite, in the first instance, to wash it thoroughly until the filtrate no longer becomes turbid on the addition of chloride of calcium, so that no trace of fluoride of sodium may be left. Geologically the conditions are different. If water, holding in solution an alkaline fluoride, penetrates through rocks, the formation of the sparingly soluble earthy fluorides will continue as long as the infiltration, and they would be removed only if pure water were afterwards to filter through the rock.

† The presence of fluoride of calcium in the residue might perhaps have been more distinctly recognized if Wilson's method of testing for fluorine had been adopted.

‡ English edition, i, 14, No. 26.

non-crystalline mass resembling gum; it combines with alkaline fluorides producing double salts. There appear to be several different double compounds of fluoride of aluminum, and fluoride of potassium.* Hydrated alumina is dissolved when digested with a dilute solution of acid fluoride of potassium, and by a further addition of alumina, the double fluoride of potassium and aluminum is precipitated, and there remains in solution a neutral fluoride of potassium. By boiling the liquid and precipitate, there is formed on concentration a basic double salt, and this with such energy that potash is liberated. This strong affinity of aluminum for fluorine and potassium, is, as Berzelius remarks, worthy the attention of chemists; because if potash is used in the analysis of a mineral containing aluminum and fluorine, this double salt is always precipitated along with the alumina. This strong affinity has likewise a special geological interest, inasmuch as it may be assumed that the fluorine in mica is thus combined.

The double fluoride of sodium and aluminum presents perfectly analogous characters, with the exception that it is decidedly less soluble. When hydrated alumina is digested with fluoride of sodium, the liquid becomes alkaline much more readily than when fluoride of potassium is used. The double fluoride of lithium and aluminum gives, in like manner, a compound which is very sparingly soluble in water. It may, therefore, be conjectured that mica may contain not only the double fluoride of aluminum and potassium, but also the corresponding double fluorides of sodium or lithium. The double fluoride of aluminum and potassium may be considered most frequent in mica, since potash is the predominating alkali in that mineral; and the removal of fluorine by decomposition, would be more probable if it existed in the state of double fluoride of aluminum and potassium, since it is more easily soluble than the corresponding double fluorides of sodium and lithium.

The double fluoride of aluminum and sodium occurs native as cryolite, in gneiss, in layers bounded by thin strata of mica, and associated with hydrated oxide of iron, spathic iron ore, iron pyrites, copper pyrites, galena, quartz, and felspar. There can be no doubt that the minerals associated with cryolite were formed in the wet way, and therefore the formation of cryolite must be regarded as similar. Moreover, as mica occurs in the immediate vicinity, it is probable that this mineral has contributed the material for the formation of cryolite.

* Berzelius. *Lehrbuch der Chemie*. 5th ed. iii, 465.

Hydrated alumina—diaspore, gibbsite—occurs very rarely native. It was, therefore, important to ascertain whether any of the minerals containing alumina and of frequent occurrence, would be decomposed by alkaline fluorides and yield fluoride of aluminum. Since artificial silicate of alumina is decomposed by solution of fluoride of potassium,* such an action may be supposed to be exercised upon native silicates of alumina, and, as silicate of alumina is very abundant in the form of clay and kaolin, the production of fluoride of aluminum in this way may be easily understood.

At Monzoni, in the Tyrol, on the Dualta la Toja, in the Pellegrin, and at Oxbow, in the State of New York, mica has been found decomposed and converted into steatite. A similar change was observed by Blum in a specimen of granite, said to be from the district of Brünn.† The mica of the granite at Thursheim, in the Fichtelgebirge, is often found to be converted into a compact, soft, steatitic mass of a dark green colour.

Steatite does not contain any traces of fluorine or of alkalies, so that in the decomposition of mica these constituents must be removed. Alumina is likewise removed, either wholly or for the most part; it is present only in a few kinds of steatite, and then in very minute proportion. If now the alkaline metals, aluminum and fluorine, which have so great a tendency to the formation of double compounds, were removed from the mica, there is an increased probability that quantities of the metals corresponding to the fluorine present existed in the mica as double fluorides.

If the three equivalents of fluoride of sodium in cryolite were displaced by three equivalents of bibasic silicate of alumina, the

* English edition, i, No. 23. This reaction was ascertained as follows. Silica, prepared by decomposing fluoride of silicium, was dissolved in potash, and acetic acid added until there was a slight precipitation of silica, which was re-dissolved by a few drops of the solution, to which acetic acid had not been added. This solution was mixed with solution of alum, and the bulky white precipitate of silicate of alumina washed and dried. When this silicate of alumina was treated with solution of fluoride of potassium, the liquid acquired an alkaline reaction, which was increased by heat so much, as perfectly to restore the blue colour of reddened litmus paper. By this reaction there are formed fluoride of aluminum and silicate of potash, to the latter of which the alkalinity of the liquid is due. The fluoride of aluminum was washed until the filtrate no longer gave any reaction with chloride of calcium, and was then treated with sulphuric acid, but no indication of the presence of fluorine was observed. Either the fluoride of aluminum had been removed by the washing, or fluoride of silicium was produced by the action of the sulphuric acid in consequence of the presence of undecomposed silicate of alumina. The presence of silicate of alumina was indeed evident from the separation of silica in the sulphuric acid solution obtained when testing for fluorine.

† Die Pseudomorphosen, p. 132, and Erster Nachtrag, p. 73.

mineral pyknite might be formed, and if at the same time a portion of the fluorine combined with aluminum were removed in combination with fluoride of sodium as acid fluoride, there would remain a basic fluoride of aluminum, which, together with the bibasic silicate of alumina, might form topaz. The localities in which topaz is found favours the opinion that it is produced in the wet way. This is the case with topaz occurring in dykes and nests in clay-slate, associated with such minerals as brown hematite, iron-spar, hematite, copper pyrites, arsenical pyrites, fluor-spar, &c., which have been formed in the wet way; also with the small yellow crystals of topaz in the beds of tin ore at Schoenfeld and Schlackenwalde; in druses of quartz, fluor-spar, or tin ore associated with apatite, copper pyrites, and iron-spar, or as part of a conglomerate in which fluor-spar or tin ore is sometimes found, and the interstices of which are commonly filled with steinmark. The Brazilian topaz again occurs together with quartz, euclase and steinmark in nests filled with brown hematite and imbedded in quartz.* Haidinger† points out the very interesting fact that lithia mica, which contains a remarkably large proportion of fluorine, appears in most instances to be associated with topaz.

No one will doubt the possibility that in the simultaneous decomposition of the felspar and mica of a granitic rock, kaolin may be separated from the former, and from the latter alkaline fluorides, or double fluorides of aluminum, and alkaline metals; or, to take a simpler case, that, by the action of fluoride of potassium upon kaolin, basic fluoride of aluminum with silicate of alumina, or topaz, may be formed.‡

The specific gravity of topaz is 3.5, while that of kaolin is 2.2, so that in the supposed conversion of felspar into topaz there would be a contraction affording ample room for the new mineral.

The occurrence of topaz in detritus, consisting of decomposed granite, at Avon-hill and at Invercauld in Scotland, in granite in Brazil, and imbedded in yellow clay in the drusy cavities of granite upon the Ilmen mountains, furnishes evidence in favour of the opinion that kaolin may actually be converted into topaz. It is probable that the topaz in the so-called topaz-rock had a

* Leonhard's Handwörterbuch, p. 507.

† Poggendorff's Annalen VI, 217.

‡ By passing fluoride of silicium over lime at a red heat, Daubré obtained a mass presenting chemical characters, and a composition similar to those of topaz; the specific gravity was 3.49. Annal des Mines (4), xix, 684. With regard to this experiment, see the remarks on the artificial production of apatite by a similar process. Chap. xxii.

similar origin; and also, that the topaz in the erupted masses at Vesuvius were formed in like manner at a subsequent period by alteration of mica and felspar.

The topaz in which there are cavities containing crystals that dissolve on the application of heat and are again formed on cooling have most decidedly been produced in the wet way.* Topaz occurs very frequently in an altered state in steinmark and in steatite; it is moreover very frequently associated with the former mineral,† and in this case it is self-evident that the alteration took place in the wet way. All that has been said of topaz is likewise applicable with regard to the formation of pyknite. This mineral, which occurs at the Zinnwald, in Bohemia, upon veins of tin-ore situated in gneiss, is in like manner found converted into steatite, and at the same place topaz occurs which has undergone conversion into steatite.

CHAPTER XXI.

BORACIC ACID AND BORATES.

THE gas which is constantly evolved from the Suffioni at Monte Cerboli, Castelnuovo, Sasso, &c., in Tuscany, was found by Payen‡ to consist of—

Carbonic acid	....	....	57·30
Nitrogen	....	....	34·81
Oxygen	....	....	6·57
Sulphuric acid	....	....	1·32
			<hr/>
			100·00

The substances which are condensed and carried away by the vapour are water, clay, (?) sulphates of lime, ammonia, alumina and peroxide of iron, hydrochloric acid and organic substance having a fishy odour. Sometimes the vapour is mixed with a little boracic acid, and wherever it penetrates narrow clefts or

* Twenty years since, Brewster found two new liquids in the cavities of crystallized topaz and other minerals. One of these liquids is very volatile, and so expansible that for the same increase of temperature it expands twenty times as much as water. The other liquid is denser, occupying the angles and narrow parts of the cavities. The cavities in which the soluble crystals are found are of a different kind.

† Blum die Pseudomorphosen, p. 66 and 129.

‡ Annal de Chim. et de Phys. 3 Sér. V. 247.

porous substances sulphur is deposited. The temperature of the vapour is about 208° or 212° F.

At the margin of the lagunes, around which the vapour issues, a saline mass is deposited, consisting chiefly of boracic acid, and containing besides ammoniacal salts, borates and sulphates of alumina and of peroxide of iron.

Boracic acid was discovered in the Suffioni in 1777 by Peter Höffer; and it has since become an object of public industry. Several fruitless attempts to procure the acid were made in the first instance, until in 1818 de Larderel* contrived a mode of condensing the vapour containing boracic acid, and at the same time to employ it as a source of heat for evaporating to crystallization the solution of boracic acid.

The quantity of boracic acid obtained in 1845 amounted to 885·000 kilogrammes, and in the following year to 1,000,000 kilogrammes.†

According to Wittstein's analysis, the commercial acid contains 76·49 per cent. crystalline boracic acid, and 23·51 per cent. foreign admixture, consisting of sulphates of ammonia, magnesia, lime, soda, potash, peroxide of iron, alumina, and oxide of manganese, together with chloride of ammonium, sulphuric acid, silicic acid, and traces of organic substances.

Boracic acid is easily volatilized by water vapour; so that when a solution of it is distilled the distillate is found to contain a little boracic acid: In evaporating a solution of boracic acid at a temperature of 145° F., I found that some of the acid was deposited upon the paper with which the dish was covered. When the crystalline acid is dried at 212° F., and a current of dry air passed over it at the same time, a small quantity is sublimed.

The opinions put forward by Payen, that boracic acid originates either from the action of water vapour upon deposits of it at great depths below the surface, or from the action of sea water upon sulphide of boron, are quite inadequate to account for the appearance of this substance. The reactions which any substance may present, cannot be taken as explanatory of geological phenomena unless the substance actually occurs in a native state, and the conditions of the particular reactions may reasonably be supposed to obtain in the case for which explanation is sought. Now boracic acid is never met with in a free state in any rock; it is known only as a deposit from hot springs or from vaporous

* Compt. rend. xxiii, No. 7.

† See Daubeny's description of active and extinct volcanoes, 2nd. Ed. p. 156.

exhalations. Besides the localities already mentioned, it is found only in the chief crater in Vulcano, one of the Lipari islands, where it is deposited upon sulphur by hot water vapour issuing from clefts, and generally impregnated with sulphuretted hydrogen. Moreover, it is difficult to imagine how boracic acid could be deposited in rocks without entering into combination with the bases they contain; and the assumption that sulphide of boron exists in the interior of the earth is wholly without foundation.

According to Bolley,* solution of borax disengages ammonia from solution of chloride of ammonium. Boracite and datolite give the same reaction. Now, in volcanic regions chloride of ammonium occurs very frequently and abundantly, and the production of boracic acid might easily be accounted for if it could be shown that some mineral containing boracic acid existed there likewise. Borax is perfectly decomposed when the chloride of ammonium is in excess, and this would probably be the case with the other borates.

The borates of magnesia lose a portion of boracic acid, together with water of crystallization, when heated, and the acid may be partially separated by boiling with water for a long time. Water distilled from borate of protoxide of iron did not at first contain any boracic acid; but when the distillation was continued to dryness the last portions of water contained an appreciable quantity of the acid. When, on the contrary, a solution of basic borate of soda was boiled in a retort, the distillate did not contain a trace of boracic acid, even when the salt became quite dry. Therefore all borates are not decomposed by water vapour, and least of all those which are basic.

This volatilization of boracic acid from borates, together with the vapour of water of crystallization, would probably be found more general if experiments were made upon other borates, and would justify the conjecture that the boracic acid of the Suffioni in Tuscany and Vulcano originates in this way.

There can be no doubt that rocks containing borates, would yield boracic acid to water at the temperature of ebullition, especially if there were any amount of pressure, and the boracic acid thus separated, would come to the surface with the vapour of water. The rocks thus acted upon may contain only a small quantity of borates, since in the Suffioni, the proportion of boracic acid to water vapour is but small.

The presence of sulphuretted hydrogen in this vapour is

* *Annal. der Chemie und Pharmacie*, lxxviii, 122.

probably accidental. The vapour contains sulphates and organic substance, by the reaction of which it might be produced, and the presence of carbonic acid seems to show that this has taken place. The vapour likewise contains oxygen, which is present both in sea water and in that of springs, and the sulphuric acid of the vapour may have been formed by direct oxidation of sulphuretted hydrogen. Again, the deposition of sulphur, where the vapour penetrates through narrow clefts, shows that sulphuretted hydrogen comes quite to the surface, and that it is only partially oxidized during its ascent. The carbonate of lime in the neighbourhood of the clefts is converted into gypsum to a considerable thickness by the sulphuric acid, especially at the lagunes of Monte Cerboli, and of Castelnuovo.*

The large proportion of sulphate of ammonia, (8·5 per cent.) in the boracic acid of commerce is surprising. This ammonia is no doubt formed by the decomposition of organic substances.

It would seem that the substances present in the vapour of the Suffioni are produced at no very great depth below the surface, for in the neighbourhood of the Lago de Monte Rotondo, a temperature of 212° F. has been found to exist at from 45 to 60 feet below the surface.

The processes of chemical alteration taking place beneath the crater of Vulcano may, according to the statements of Hoffmann, depend upon conditions very similar to those existing in Tuscany. There, likewise, sulphuretted hydrogen is associated with the boracic acid, and it would appear, in much greater quantity, since the fissures through which the vapour issues are thickly lined with sulphur, which is in sufficient quantity to be collected for sale. The occurrence of druses and incrustations of gypsum, as well as the vitriol and clays used in the manufacture of alum, likewise prove the partial oxidation of sulphur.†

The effects of water vapour charged with sulphuretted hydrogen are shown in the rocks decomposed throughout their entire mass, though still retaining their coherence and solidity. Even hard black obsidian is converted into a snow-white compact claystone, in which a few brilliant black grains are distributed, while sulphur is deposited in the clefts either in masses or druses.

Even at depths where the oxidation of sulphuretted hydrogen cannot take place at all, or only to a very small extent, and where

* *Bullet. Geol.* vi, 147.

† The very profitable factory at that place yields daily, besides boracic acid and chloride of ammonium, about 1,700 pounds of refined sulphur, and about 600 pounds of pure alum. Hoffmann, *Op. cit.* p. 168.]

consequently the decomposing action of sulphuric acid is not exercised, it is probable that minerals containing boracic acid may still be unable to withstand the action of water vapour, particularly if the temperature is above the boiling point.

These exhalations may occur wherever water vapour comes in contact with rocks containing borates susceptible of decomposition; for when water penetrates to a depth where the temperature is sufficient for its conversion into vapour, boracic acid would be extracted from such rocks, and appear in the form of an exhalation at the surface. Volcanic regions are peculiarly favourable to this phenomenon; because the strata being fissured to great depths, admit of a copious penetration of water downwards, and because a high temperature frequently exists at moderate depths below the surface, as in the crater of Vulcano, owing probably to the presence of ignited remains of former lava streams.

The water vapour of the lagunes of Monte Cerboli issues from fissures in limestone. The fummachiæ at the Possera, a tributary of the Cicina, descending from Castelnuovo, are surrounded chiefly by greyish-blue plastic clay. The hill separating the fummachiæ from the Possera consists of compact limestone. On the opposite side of this river columns of vapour issue from tilted strata of limestone with a loud hissing noise. At the equally great fummachiæ of Castelnuovo the predominating rock is compact granular sandstone, with marly cement alternating with thick strata of slate, marl, and clay; and covered towards the east with limestone. Here the fummachiæ are situated in a narrow row as if upon a fissure, probably a quarter of a mile in length. Hoffmann,* to whom we are indebted for these descriptions, distinctly observed, while looking down from the height, that these fummachiæ and those of Monte Cerboli are situated upon different declivities of the same hill, and probably upon the same fissure. They both yield boracic acid. H. Coquard† states that many other fummachiæ occur in the woods south-west of Serrazano, and are distributed over an extent from $28^{\circ} 27'$ to $28^{\circ} 40'$ long. and $43^{\circ} 10'$ to $43^{\circ} 15'$ lat.

The opinion that boracite exists in the limestone rocks from which the Suffioni issue is not liable to much objection. Its occurrence in gypsum and anhydrite renders this view more probable, since the presence of sulphuretted hydrogen in the vapour presupposes the presence of sulphates, of which sulphate

* Karsten and v. Dechen's Archiv. xii, 19.

† Bullet. Geol. vi, 147.

of lime occurs most frequently. Moreover, since the compounds of boracic acid and magnesia when exposed to heat lose their boracic acid together with water of crystallization; anhydrous boracite might, by the joint action of heat and water vapour, yield its boracic acid; more especially if carbonic acid were present, as in the Suffioni, for its affinity for magnesia would facilitate the decomposition.

It can scarcely be supposed that exhalations of boracic acid are limited to the phenomena at present known in Tuscany and Vulcano. They no doubt occur wherever hot water vapour traverses rocks containing borates; but since the exhalation of hot vapour is peculiar to volcanic regions, it may be that boracic acid occurs in like manner only in these localities. During volcanic eruptions boracic acid may be carried into the atmosphere in a proportionately large quantity, and be again brought to the surface of the earth by rain.

Several physical characters of the Suffioni with which we have been made acquainted by Larderel are worthy of notice. When the lagunes are so deep that the vapour is unable to overcome the pressure of the column of water it takes some other way of escape where the resistance is less. In this way the vapour sometimes disappears entirely at a spot where it has been evolved regularly for as much as a year, and appears again at a distance of 90 or 100 feet.

The dimensions of the lagunes vary very much. The smaller ones are generally a hundred feet in circumference and four feet deep. There are some, however, which have a circumference of five hundred or even a thousand feet, with a depth of from fifteen to twenty-five feet. The latter contain several openings from which the vapour ascends, from three or five to fifteen. At a depth of twenty-five feet the vapour will have a temperature of nearly 212° F., and therefore it must come from a depth where there is at least this temperature.

The following minerals contain boracic acid:—tourmaline, from 2 to 12 per cent.; axinite, from 2 to 6 per cent.; datholite—borate of lime with silicate of lime,—botryolite, borax, boracite—borate of magnesia,—hydro-boracite—borate of lime and magnesia. In the arid plains of Iquique, in South America, delicate snow-white crystals of hydrated borate of lime are found in large quantity.*

Tourmaline is the only mineral containing boracic acid, that occurs in crystalline rocks, especially granite; the others occur

* Silliman's Journ. lxvii, 215.

partly on dykes, in clefts, and drusy cavities,—axinite and datholite;—partly in magnetic iron ore—datholite and botryolite,—partly imbedded in gypsum and anhydrite—boracite. The fact that boracite was obtained in large quantity from a depth of about 1,400 feet in the bore, previously mentioned, at Stassfurth may be an instance of the latter kind of occurrence.* Borax, or tinkal, is found upon the surface of the soil and along the banks of the Mapin Monta-bi, in Thibet. All these minerals present such evident indications of having been formed in the wet way that it is quite unnecessary to bring forward any other evidence in support of this opinion, more particularly as traces of boracic acid have recently been detected in the water of the Kochbrunnen, at Wiesbaden, in that of the Kaiserquelle, at Aix-la-Chapelle,† and in that of the Schlossbrunnen, at Carlsbad.‡ A much larger quantity has likewise been found in the water of the springs at Olette, in the Pyrenees.§ There is, moreover, reason to expect that many more such instances of the occurrence of boracic acid will be made known now that attention is directed to it, for the borates of the earthy and metallic bases are to a certain extent soluble. Judging from analogy, boracic acid must be considered to exist in the water of rivers and of the sea. The quantity, however, would be very small, and probably would escape detection. The boracite associated with gypsum and with rock salt cannot have been derived from any other source than sea water. With regard to tourmaline, its mode of formation coincides with that of the other constituents of granite of which mention will be made subsequently. The separation of boracic acid during the alteration of tourmaline is evidenced by the comparison of the composition of this mineral and that of the minerals which are pseudomorphous after it, such as mica, chlorite, and steatite. Rammelsbeg analyzed such a pseudomorphous mica, and found that it contained no boracic acid. Chlorite and steatite do not contain either boracic acid or alkalies; so that there is good reason to suppose that in the production of these minerals by alteration of tourmaline, the boracic acid and alkalies were separated in combination. In the alteration of soda into mica tourmaline, therefore, borate of soda would be separated; for only very minute quantities of either boracic acid or soda are found in mica.

* Karsten.—Archiv. für Mineralogie, xxi, 491.

† Fresenius and Wildenstein.—Journ. für praktische Chemie, xlv, 153.

‡ Communicated by M. Göttl, in Carlsbad.

§ Peligot.—L'Institut. 1853, No. 196.

CHAPTER XXII.

PHOSPHATES.

THE following minerals contain or consist of phosphates: *—
Apatite, the most frequent native phosphate; it occurs in granite, hornblende rock, granular limestone, talcose-, micaceous-, chloritic-, and carboniferous schist; in dolerite, nepheline rock, basalt, glassy felspar rock, and in lava; likewise in metalliferous veins traversing granite, diorite, gneiss, porphyry, clay-slate, and in beds of magnetic iron ore.† The small green granules in the chalk of Cape la Neve, consist of apatite, according to Berthier.‡

Phosphorite, or the earthy variety of apatite, frequently occurs in beds, distinctly indicating deposition from water. It is found at Pilgrimsreuth, on the declivity of the Füstelgebirge, in layers two or three inches thick in a sandy clay, beneath bituminous shale, constituting the underlying strata of brown coal. This phosphorite is much more impure than that which occurs in nests in the basalt of the same locality, and contains fluorine.§ There is near Hanau, a layer of phosphorite, four or five inches thick, underlying a soil composed of disintegrated dolerite. C. Bromeis is of opinion that the phosphate of lime was derived by decomposition, from basalt and dolerite, which in the unaltered state contain apatite.|| Krantz found on the surface of trachyte-conglomerate on the southern declivity of the Siebengebirge, pieces of compact granular phosphorite, containing in small drusy cavities, transparent crystals of apatite. Neither fluorine nor chlorine could be detected in this apatite.¶ In the island of Ascension, stalactitic masses of impure phosphate of lime, occur in basalt near guano,** from which it is probably derived. At Logrossan in Estremadura, phosphorite occurs as a rock.††

* The metallic phosphates will be treated of in the chapter relating to the formation of metalliferous veins.

† The apatite of America is especially remarkable. In the district Hanemand (New York), a crystal has been found, measuring a foot in length, and weighing eighteen pounds. See *n. Jahrbuch für Mineralogie*, etc. 1849, p. 808.

‡ Schweigger's Journal, xxxiii, 469.

§ Nauck in the *Zeitschrift der deutschen geologischen Gesellschaft*, ii, 40.

|| *Ann. der Chem. und Pharm.* lxxix, 1.

¶ *Verhandlungen des naturhistorischen Vereins der preussischen Rheinlande, &c.* Jahrgang, ix, p. 563.

** Darwin, *Travels*. German Translation, i, 9.

†† *L'Institut*. 1846, No. 673.

The following phosphatic minerals are of much rarer occurrence: dihydrite—hydrated phosphate of lime;—magnesian apatite—phosphate of lime with phosphate of magnesia, chlorides fluorides, and sulphate of lime, in the Ural: wagnerite—phosphate of magnesia, with fluoride of magnesium—in the clefts of a very friable clayslate at Werfen in the Salzburg Alps; lazulite—phosphate of alumina, with phosphates of lime, magnesia, and protoxide of iron—in clefts of clay-slate: phosphate of alumina, in a cavity of a volcanic rock in Bourbon; wavellite and kakonine—phosphate of alumina, with fluoride of aluminum—in granite, and in clefts in clay-slate, silicious-slate, sandstone, brown hematite, binoxide of manganese, and the dolomite underlying the erupted masses round Vesuvius; gibbsite—amorphous hydrated phosphate of alumina—in an abandoned iron mine* in Richmond, Massachusetts; calaite—a compound of wavellite and gibbsite—in clefts in clay-slate;† amblygonite—phosphates of alumina and lithia, or soda, with fluorides of aluminum and lithium, or sodium—in the granite of Chursdorf, in Saxony; phosphate of yttrium, with traces of fluorine, in a dyke in coarse grained granite; cryptolite—phosphate of cerium, with some protoxide of iron—imbedded in the compact apatite of Arendal;‡ monazite—probably phosphates of cerium, lanthanum, etc.—and monazitoite, in a species of granite; edwardsite, and sordawalite.

Phosphoric acid may frequently be detected chemically, in rocks which do not present any indications of phosphatic minerals; and now that we have in molybdate of ammonia such a delicate test for phosphoric acid, it is probable that its existence will be recognized in many rocks where it was not suspected.

Upon the ground that almost all rocks yield, by their disintegration, soil, which is, to a greater or less degree, capable of affording nutriment to plants, and would therefore in all probability contain phosphoric acid, which is so generally essential for the growth of plants, Fownes§ examined several crystalline and volcanic rocks, for phosphoric acid. He considered that it would exist in the state of phosphate of alumina, and as this substance is soluble in dilute acids, while most silicates are not dissolved by them, he hoped to extract the phosphate of alumina by this means.

* Hermann. Journ. für prakt. Chemie, xlvii, 1.

† Likewise peganite and fischerite, which, like calaite, are hydrates of the same phosphate of alumina.

‡ Wöhler, in the Göttingischen gelehrten Anzeigen, 1845, p. 19.

§ On the existence of phosphoric acid in rocks of igneous origin. Edin. New Philos. Journ. 1844, p. 249.

He examined:—1, porcelain clay from Dartmoor:—2, lava from the Rhine, probably that of Niedermendig:—3, trachyte from the Drachenfels:—4, lava from Vesuvius:—5, basalt from Cavedale in Derbyshire:—6, basalt from Dudley:—7, old porphyritic lava, containing numerous crystals of hornblende, from Vesuvius:—8, tufa from Vesuvius:—9, hornblende rock, from Arendal.

The indications of phosphoric acid in the first four rocks, were unequivocal; in 5 and 6, they were slighter, but indubitable; in the lava, 7, less than in 8 and 9.

Kersten* and Elsner† examined several of these rocks, but failed in detecting phosphoric acid. In the basalt of the Blaue-Koppe, at the Meissner, Deck found‡ a mineral, having the composition of apatite, and, according to Bergmann,§ the lava of Niedermendig, contains 1·8 per cent. phosphoric acid, and, according to Rammelsberg,|| the basalt of Engelhaus, near Carlsbad, contains 0·44 per cent. phosphoric acid. He considers that the acid is combined with lime, as apatite.

The luxuriant vegetation covering the numerous basaltic, and lava hills, round the Laacher See, furnishes indirect evidence of the presence of phosphoric acid in these rocks. A rock, upon which has been produced, during ages, vast quantities of timber, chiefly beech, in the ash of which there is phosphate of lime, magnesia, peroxide of iron, protoxide of manganese, and alumina, amounting, according to Hartwig, to 10·1 per. cent., must contain phosphoric acid, for there is no other source whence it has been derived. The same circumstance is presented in the Sieben-gebirge. Without the evidence of analysis, it may be inferred that the trachyte of Drachenfels, contains phosphoric acid. As a general rule, the analysis of the ash of plants growing upon rocks, without the aid of manure, will furnish satisfactory evidence of the presence in those rocks of substances, whose amount in the rocks is too minute to be recognized directly.

The presence of apatite in the lava above mentioned, is less remarkable, since a couple of very fine apatite crystals were found¶ in a volcanic bomb, from the shore of the Laacher See, not very far from the lava stream at Niedermendig. Apatite likewise

* Journ. für prakt. Chem. xxxiv, 366.

† Ibid., xxxv, 315.

‡ Chem. Gaz. 1848, p. 344.

§ Karsten's and v. Dechen's Archiv. xxi, 41.

|| Handwörterbuch, Suppl. iv, 16.

¶ Nöggerath. Die Gebirge in Rheinland Westphalen, i, 366.

occurs in the drusy cavities of one of the lava streams at Vesuvius, below Monte di Somma. Since, moreover, this mineral is found in basalt, and very frequently in granite, we cannot doubt the possibility of phosphoric acid being present in the basalt examined by Fownes, and in porcelain clay, which may originate from granite, containing apatite. The observation of Breithaupt, and Harkort, that some species of felspar, contain phosphoric acid* besides fluorine, may also be adduced in evidence of the existence of phosphoric acid in trachyte.

Of the lavas of Rhia, Vesuvius, Monte Nuovo, Arso, Stromboli, and of Hecla, and other volcanoes in Iceland, there are fourteen analyses, part of them made by trustworthy chemists, but the presence of phosphoric acid is not mentioned in any instance, probably, however, it was not looked for.

In consequence of the interest that the results obtained by Fownes, have, in relation to agricultural chemistry, Sullivan† was induced to examine several rocks for phosphoric acid, and succeeded in detecting a considerable quantity of it in granite, from the Odenwald, and from Scotland. Gneiss from the Odenwald, was found to contain so much, as to be recognizable by the reaction with nitrate of silver. Chloritic schist contained a sensible quantity; augite, and porphyry, more than a trace. Basalt, from the Giant's Causeway, contained so much, that it could be precipitated as ammonia phosphate of magnesia. Two ounces of diorite, containing augite, from the Lahnthal, gave enough to be recognized by means of nitrate of silver. A variety of hypersthene occurring in the diorite from the Lahnthal, contained traces; the trap of Norderland, belonging to greenstone, a variable quantity; the phonolite of the Rhone, somewhat more than a trace; phonolite tuff of the same locality, the pumice of the Laacher See, and the obsidian of Lipari, a large quantity; the mica of Spessart, very little; Russian mica, more; crystallized hornblende, very small traces; crystallized augite, from the Rhone, traces; olivine, from the Vogelsberg, so much as to be recognizable, by means of nitrate of silver; sodalite, from Vesuvius, traces; lepidolite, so much that it must have been an essential constituent of the mineral. East Indian tinkal contains a very large quantity, sometimes as much as 2.33 per cent.; datholite,‡ from Andreasberg (Harz), and from North America, traces.

* Poggendorff Ann. ix, 182.

† Journ. für prakt. Chemie, xxxvi, 251.

‡ The occurrence of phosphoric acid together with boracic acid, naturally suggest that it may exist in the Suffioni and in other minerals containing boracic acid.

Thomson* has likewise ascertained the presence of phosphoric acid, in most earthy minerals.

The circumstance that phosphoric acid is associated with fluorine in minerals, led Berzelius to the discovery of phosphates of lime and alumina in the water, and deposits of the hot springs at Carlsbad.† The phosphoric acid contained in these, would yield 55·6 pounds of apatite yearly. Since that time, phosphoric acid has been found in the water of numerous mineral, and fresh springs. The proportion of phosphate of lime and of magnesia, in the water of an artesian well at Wildegg, in the Canton Argau (Switzerland), is nearly five times greater than in the water of the Carlsbad springs. Phosphate of lime must be regarded as present in all water running into the sea ; it has already been detected in the water of the Dee, and of the Don ; and it will most likely be found in the water of all rivers. Phosphate of lime has been shown to be present in sea water, by Clemm‡ and Forchhammer.§

The solubility of phosphate of lime in carbonated water, was ascertained in the following experiments, by introducing the finely powdered substance into water, and passing a current of carbonic acid gas through it for several hours. The weight of the dissolved substance was always determined in the anhydrous condition.

	Water saturated with carbonic acid.
Apatite dissolves in	393,000 parts.
Apatite, after brisk agitation with the liquid, in	96,570 „
Artificial neutral phosphate, freshly precipitated, in	1,503 „
Same salt, after thorough drying in air, in	2,042 „
Artificial basic phosphate, freshly precipitated, in....	1,102|| „
Same salt, after thorough drying in air, in	5,432 „
„ „ „ ignition, in	13,115 „
Burnt bones, which had been exposed for several years, and had absorbed carbonic acid}	2,823¶ „
Fresh ox bones, in shavings	4,610**,.
„ „ after being digested for eighteen days in water saturated with carbonic acid}	4,030 „

* In the German edition I have brought forward probable reasons why phosphoric acid has been found in the rocks mentioned in some instances, but no tin others.

† Gilbert's Annalen, lxxiv, 136.

‡ Journ. für prakt. Chemie, xxxiv, 185.

§ Berzelius, Jahresbericht, xxvi, 393.

|| Lassaigue—Comptes rendus, xxiii, 1019—found it dissolved in 1333 parts.

¶ According to Liebig—Ann. der Chem. und Pharm. lxi, 128—only 1,509 parts of water saturated with carbonic acid are required.

** Lassaigue—Journ. Chim. Méd. 3 Sér. iii, ii, and iv, 536—found 6,024 parts necessary for solution.

	Water saturated with carbonic acid.
The same, after being digested in the water for the same time	2,981 „
Boiled ox bones, after being digested in the water for the same time	3,643 „
Fossil bones that had been buried at least thirty years	5,400* „
Ivory shaving, without agitation	36,620 „
„ filings, shaken....	8,152 „
„ „ „	5,260 „

These results show how remarkably the solubility of phosphate of lime varies, according to its source, and the kind of admixtures present. Apatite requires 356 times as much liquid for its solution, as the same salt artificially prepared; but it must not be overlooked, that apatite is a compound of phosphate of lime with chloride, and fluoride of calcium, which behaves towards water, differently from phosphate of lime.

The greater solubility of bones than of apatite is a very wise arrangement. The phosphate of lime in a grown ox, will have been transferred within a few years, from the soil, through plants, into the structure of the animal, and if its bones were as sparingly soluble as apatite, a very long interval would elapse before the phosphate were again returned to the soil. We may suppose a bone one inch in thickness, and lying upon the ground, to come in contact with as much meteoric water, in three or four hundred years, as would suffice for its complete solution, provided the water were saturated with carbonic acid. Meteoric water, however, contains very little carbonic acid; but, on the other hand, a considerable quantity is generated in the processes of putrefaction, which take place in the soil; and although this would aid in effecting the solution of the bones, still a much longer time would be requisite in most instances, for perfect solution of bones.†

It is deserving of notice, that basic phosphate of lime dissolves in 3150 parts of water, containing $\frac{1}{12}$ by weight of chloride of sodium. The presence of chloride of ammonium, increases the solubility still more. Now, since chloride of sodium is so frequently

* Lassaigne—Chim. Méd. 3 Sér. iii, ii, and iv—found that bones which had been probably twenty years under ground required only 3,333 parts of water saturated with carbonic acid.

† Since the solubility of phosphate of lime depends upon the presence of carbonic acid in the water, it follows that bone requires for solution ten parts of carbonic acid. Thus, the quantity of carbonic acid requisite for the solution of bones is by no means large; and in situations where carbonic acid is copiously and continuously evolved in putrefaction, their solution may take place rapidly.

present in water, its solvent relation to phosphate of lime will be proportionably greater; and it would be particularly interesting to ascertain whether the solubility of apatite is affected by the presence of chloride of sodium.

The occurrence of apatite in granite, and other crystalline rocks, usually regarded as of igneous origin, as well as in lava, etc., which is undoubtedly an igneous rock, has led to the opinion that apatite was formed in the same manner. With regard to its occurrence in granite, I made the following experiments, at a time when I still considered granite to be an igneous rock.

Equal quantities of phosphate of lime and silicate of soda were submitted to a high temperature in a platinum crucible, insufficient however to effect fusion. The cold mass, treated with boiling water, yielded phosphate of soda; showing that at a red heat the two salts suffered mutual decomposition.

Finely powdered granite (100 parts), ignited with basic phosphate of lime (15 parts), gave a mass from which boiling water did not extract anything. When the granite was ignited with 15 per cent. of anhydrous phosphate of soda, and the soluble portion of the resulting mass extracted by boiling water, only a trace of insoluble phosphate—probably phosphate of iron—was found in the residuc.

Lastly, when anhydrous phosphate of soda and silicate of lime, in equal parts, were ignited, and the soluble portion of the mass extracted by hot water, a residuc was left, amounting to 59·35 per cent., and consisting of 25·52 basic phosphate of lime, and 33·83 silica, and silicate of lime.

These experiments show that when silica, alkalies, phosphoric acid, and lime, are present in a melted mass, the latter two will be separated as phosphate of lime. The apatite in lava may therefore have crystallized during the solidification of the mass. It cannot be determined whether this has been the case, or whether, as is more likely, the phosphate of lime in the lava was not gradually dissolved by water, from which it crystallized as apatite. This mode of formation is rendered still more probable by the fact that apatite is found only in old porous lava, while lava, in which it is not recognizable mineralogically, yields by disintegration, soil, capable of supporting the growth of plants containing phosphoric acid, as well as the lava which evidently contains apatite. Moreover, if it were possible for apatite to crystallize out of melted lava, it would probably be found in the most recent lava streams; especially as the quantity of phosphoric acid was found to be

greater in recent lava, than in the older kinds. Again, the phosphate of lime in plants growing upon lava must have been extracted by water; through which medium alone the inorganic constituents are transferred to the plant organism.*

The residue obtained by evaporating to dryness a concentrated solution of chloride of calcium, mixed with fresh precipitated phosphate of lime, gives, when exposed to a strong heat, hydrochloric acid, and when the mass is well washed, there remains a compound of phosphate of lime, and chloride of calcium, containing two equivalents of chloride of calcium more than there is in chlorapatite.

The fact that phosphoric acid undergoes modification when its salts are exposed to the influence of heat, would seem to be available for ascertaining whether phosphatic minerals have been formed under the action of heat or otherwise. Upon this ground, Bousingault† was of opinion that the phosphates occurring in the crystalline rocks would probably contain pyro-phosphoric acid; while those in more recent rocks would contain the tribasic acid: his experiments, however, have not borne out this conjecture.‡

By passing vapour of chloride of phosphorus over lime at a red heat, and treating the resulting mass with water and acetic acid successively, Daubree§ obtained a granular powder, having the composition of chlorapatite, and presenting under the microscope the crystalline form of that mineral. But such experiments, however interesting they may be in some respects, have no value for geology, unless it can be shown that the conditions are likely to have been in existence, and in this instance there is not the slightest probability that chloride of phosphorus has played any part in the formation of minerals. Chlorine and phosphorus are substances whose isolation involves complicated and highly artificial operations, which may reasonably be regarded as impossible in the chemistry of geology.

C. Bœdeker|| found that when a portion of the phosphate of lime, obtained by precipitating a solution of chloride of calcium

* Researches that have been made by Lassaigne—Journ. Chim. Méd. 3 Sér. iv, 534; and Ann. de Chim. et de Phys. 3 Sér. xxv, 346—show that phosphate of lime is conveyed into the plant organism by water saturated with carbonic acid. Dumas—Comptes Rendus—xxiii 1018—holds the same opinion.

† Ann. de chim. et de phys. lv, 185.

‡ In the German edition—i, 701 and 702—I have shown that the examination of phosphatic minerals cannot determine whether they have been formed by fusion, or in the wet way.

§ Ann. des Mines. 4 Sér. xix, 684.

|| Ann. der Chem. und Pharm. lxix, 206.

by a slight excess of phosphate of soda, is dissolved in the smallest possible quantity of hydrochloric acid, and then mixed with the remaining portion, a precipitate is formed, which after two days appears under the microscope in the form of very thin tabular rhombic prisms.

By passing carbonic acid through water in which fresh precipitated phosphate of lime was suspended, Percy* obtained on evaporation of the clear liquid at the ordinary temperature, fine scales. This phosphate of lime, as well as that obtained by Boedeker, consists of two equivalents of lime with one equivalent of phosphoric acid, and five equivalents of water.

Both these processes have geological interest, because they furnish crystalline hydrated phosphate of lime, and because they may, with some modification, be supposed to take place in rocks. Percy obtained by the same method phosphate of magnesia in beautiful crystals, which effloresced in warm air; it was not, however, analysed.

It was for a long time a singular anomaly that no instances were known either of pseudomorphous apatite or of other pseudomorphous minerals after apatite. However, pseudomorphous apatite after an unknown mineral, has been made known by Zippe; it occurs in the Schlaggenwald in Bohemia. In one specimen of this apatite Breithaupt recognized the form of sulphate of iron. Iron pyrites occurs in the beds of tin ore of the same locality; but notwithstanding its easy conversion into sulphate of iron, and the solubility of this substance,† it is difficult to perceive how water could have brought phosphate of lime in sufficient quantity to have retained the form of such a soluble salt. Sillim‡ states, that in his collection there are specimens of pseudomorphous apatite after pyromorphite from the Chur-prinz mine at Freiberg; but he does not give any further description of them.

Apatite is anhydrous, while both the artificial basic phosphate of lime, which has the same composition, and the neutral phosphate of lime are hydrated. Dihydrate is an instance of an hydrated native phosphate. The presence of water in any mineral is a sufficient indication that the mineral cannot have been formed by fusion, especially when that water may be expelled by a gentle heat. On the other hand, however, it cannot be inferred that anhydrous minerals must be products of

* Phil. Mag. 3 Ser., xxvi, 194.

† Blum. Zweiter Nachtrag zu den Pseudomorphosen, p. 137.

‡ Neues Jahrbuch für Mineralogie, &c. 1848, p. 388.

fusion, because some salts crystallize from water solutions in the anhydrous state.

Next to lime, alumina is found most frequently in combination with phosphoric acid. In a few minerals phosphoric acid is found in combination with alumina and other bases together. Amblygonite is the only mineral in which phosphate of alumina is anhydrous. In wavellite, gibbsite, lazulite, calaite, the phosphate of alumina is hydrated. The compounds of phosphoric acid with alumina, which are obtained artificially by precipitating a salt of alumina with ordinary phosphate of soda, are likewise hydrated. H. Ludwig* prepared such a compound, which had the composition of gibbsite, and was like it, amorphous.

Magnesia occurs in combination with phosphoric acid only in the rare minerals, wagnerite and magnesian apatite, and in these instances the phosphate is anhydrous. The circumstance that the artificial salt contains water of crystallization, while wagnerite is anhydrous, may be owing to the presence of fluoride of magnesium in the latter.

Besides the phosphates of heavy metallic oxides, minerals contain phosphates of lime, magnesia, lithia, soda, alumina, yttria, zirconia—in edwardsite—cerium and lanthanum. The phosphates of baryta, strontia, glucina, and thoria, have not been met with in minerals.

The frequent association of phosphates with fluorides is worthy of notice. The latter are wanting only in monazite, edwardsite, lazulite, sordawalite, calaite, and phosphate of alumina. In apatite, phosphate of yttria, amblygonite, wavellite, and wagnerite, it may be assumed, without hesitation, that phosphoric acid and fluorine are combined with the bases and metals. In some specimens of apatite the phosphate of lime is combined with fluoride of calcium, in others with chloride of calcium, and in others again with both haloid salts.

Since the phosphates of lime dissolved in carbonated water are decomposed by alkaline carbonates,† it follows that if such water dissolves apatite from crystalline rocks, and at the same time takes up alkaline carbonates by the decomposition of felspar, the phosphate will be converted into carbonate of lime, and since phosphate of lime cannot exist in water containing carbonate of soda, the phosphoric acid of mineral water containing carbonate of soda must be combined not with lime but with soda only.

* Archiv. für Pharmacie, lix, 19.

† English edition, i, 13, No. 19.

The insoluble portion of the residue left on evaporating mineral water frequently contains phosphate of lime and phosphate of alumina, which, like the carbonates of lime, iron, and manganese, were held in solution by carbonic acid. These earthy phosphates are found even in the residue of water containing carbonate of soda; but it is difficult to say how they could exist in the presence of alkaline carbonates, or how they could have escaped decomposition during the evaporation of the water. The presence of phosphates of lime and alumina in the deposits formed by the Carlsbad springs, shows that mineral water containing phosphoric acid may deposit these phosphates when the deposition takes place, merely in consequence of the escape of carbonic acid.

The solution of the phosphates of lime in carbonic acid water gives precipitates with fluoride of sodium and ammonia. The former produces fluoride of calcium and phosphate of soda, and it is probable that fluorine is introduced in this manner into fossil bones. The precipitation of phosphate of lime by ammonia would take place in a soil when ammonia, generated in putrefaction, comes in contact with solution of phosphate of lime in carbonated water.

The analysis of wavellite by the method of Berzelius* and Fuchs† shows that phosphate of alumina cannot exist in solution with an alkaline silicate; consequently the phosphate of alumina in wavellite cannot have been formed from silicate of alumina by contact with solution of phosphate of soda. My experiments also‡ would show, that it is impossible for wavellite to have been formed by the mutual decomposition of silicate of alumina and phosphate of lime in solution.

The presence of basic phosphate of alumina in the water of the Carlsbad and several other mineral springs, renders it probable that wavellite is formed in the wet way. This is more especially the case since fluorine is associated with basic phosphate of alumina in the Carlsbad water, which may therefore furnish all the ingredients requisite for the formation of this mineral. It still remains to be ascertained from what phosphatic mineral the phosphate of alumina in the water of springs originates. The presence of phosphate of soda in water has already been pointed out, and as the soluble salts of alumina are decomposed by phos-

* Schweigger's Journ. xxvii, 63.

† Ibid. xxiv, 126.

‡ German edition, i, 720.

phate of soda, it is possible that it may originate from sulphate of alumina, which is frequently formed in beds of clay by the oxidation of iron pyrites. It is a question, however, whether the wavellite occurring in clay-slate has been formed in this way or not.

The presence of water in wavellite, as well as the occurrence of this mineral as an incrustation on the faces of clefts and cavities in brown hematite, entirely excludes the possibility of its being formed by fusion.*

Phosphate of alumina is one of the most sparingly soluble substances that are known; however, it is soluble in water saturated with carbonic acid, according to my experiments in about 6,828,000 parts. The water of the Carlsbad springs contains $\frac{1}{5125000}$ basic phosphate of alumina, or about double this quantity.

Protophosphate of iron is still less soluble than phosphate of alumina. A solution of phosphate of lime in carbonated water is decomposed by protosulphate of iron,† but since the sulphate of lime produced by the reaction is more soluble in carbonated water than any of the phosphates of lime, it remains dissolved. In like manner soluble sulphates do not produce any precipitate in the solution of phosphate.

Vivianite is very frequently found in metalliferous veins associated with iron pyrites and magnetic pyrites; it has also been found in the interior of bivalves occurring in a bed of argillaceous iron ore at Kertch, in the Crimea, and filling belemnites and gryphites in ferruginous sandstone at Mullica Hill and Allentown, in New Jersey.‡ Its association with iron pyrites on the one hand and with fossils on the other, probably justifies the inference that the iron pyrites was converted, by oxidation, into sulphate, and that the phosphate of iron was formed by the reaction of this salt with the phosphate of lime in the fossils.

* It is, indeed, found in blocks of granular limestone, said to have been ejected from Vesuvius during the eruption of 1822; but a hydrated mineral cannot be a volcanic product. There is no doubt that the wavellite in this instance was formed long after the eruption, from phosphoric acid and alumina present in the limestone; and if the limestone was derived from the Appenine strata, which are traversed by the volcanic channels, it may be inferred that the limestone did contain phosphoric acid.

† English edition, i, 14, No. 21. A solution of basic phosphate of lime in carbonated water gives a more abundant precipitate than the neutral phosphate, because the latter is less soluble than the former.

‡ In the collection made by Dr. Krantz for the University of Edinburgh, there is a specimen of vivianite occupying the interior of a muscle shell—cardium acordo—belonging to the tertiary series.

A remarkable instance of the occurrence of vivianite in the Scharley calamine mine (Silesia) shows that this mineral may be formed with the phosphoric acid of bones. At a depth of eight or nine fathoms the skeleton of a man was found, and on breaking one of the bones, crystals of vivianite became visible in the interior. A thigh-bone, when sawn through, showed three crystals of vivianite projecting from the inner surface, and four others which were loose. Upon the cut surface blueish-grey spots were visible, which appeared to be particles of vivianite, so that the formation of this mineral took place in the mass of the bone.

The length of time the bone has laid there is unknown. The working of the Scharley mine began in the 13th century, and from the locality, it may be presumed the mine was worked for lead. It is now nearly three hundred years since the working of the mine was discontinued, so that the bones would, in that case, be very old. The shaft in which they were found, might, however, have been sunk in search of calamine, in which case the bones would not be so old.*

The phosphate of copper in the Virneberg at Rheinbreitenbach, seems to have originated from oxidized copper pyrites. It is found chiefly in the outcrop of the lode, in the clay-slate rock, and in the neighbourhood of open clefts, associated with tile ore, chalcodony, and quartz. The tile ore, a mixture of earthy oxide of copper and iron ochre, has, undoubtedly, originated from the alteration of copper pyrites; for it is sometimes pseudomorphous after this mineral, and occurs in the same position. The occurrence of the phosphate of copper at the outcrop of the lode, and in the neighbourhood of fissures, clearly shows, that the water containing phosphate, probably phosphate of lime, came from the surface, whether it derived the phosphate from the rock, or from organic remains in it.

Since phosphate of lime and carbonate of iron, dissolved by carbonated water, undergo mutual decomposition,† it is possible that vivianite may be formed from carbonate of iron. Its origin in this manner is more simple; for it is unnecessary to suppose the previous oxidation of iron pyrites, in order to account for the formation of phosphate of iron. Carbonate of iron is found

* Communicated by v. Carnall, at a meeting of the physical section of the Niederrheinischen Gesellschaft at Bonn, on the 3rd December, 1846.

† English edition, i, 13, No. 20.

almost everywhere in water; and if carbonated water* containing phosphate of iron, come in contact with phosphate of lime, more or less of this substance will be dissolved, and phosphate of iron precipitated. It is very probable that the vivianite in the bones above mentioned was formed in this manner.

In localities where large quantities of bones occur, as for example, the Pampas bordering the La Plata, and where they are washed by carbonated water containing iron, it is possible that the formation of phosphate of iron might take place to a great extent, and even proceed to the complete transformation of the phosphate of lime in the bones. The remarkable bed of phosphate of iron which Dieffenbach† and Hooker‡ met with in the Antarctic regions, near the island Pain-de-Sucre, may have originated in this manner.

It is not improbable that the double phosphate of iron and manganese, which was analysed by Fuchs, and is found in granite at Zwisel, in the Baierschen Wald, originates from apatite which has been altered by water containing carbonates of iron and manganese. This mineral has a composition analogous to that of apatite, and like it contains fluorine.

When, on the other hand, carbonated water containing basic phosphate of lime in solution, comes in contact with proto-silicate of iron, it is possible that the latter salt may be decomposed by the free carbonic acid, and that in this way, proto-phosphate of iron may afterwards be formed. The vivianite in basaltic rocks, and basaltic lava, has perhaps been formed in this manner.

On account of the mutual decomposition of phosphate of lime, and protocarbonate of iron, it would be impossible for these two substances to exist together in carbonated water, supposing it to be saturated with the former salt. According to analyses hitherto made, this condition of saturation does not obtain in any instance, but on the contrary, the quantity of phosphate of lime is always very minute. In the Carlsbad water, for example, it amounts according to Berzelius, to only $\frac{1}{4500000}$, or only $\frac{1}{11}$ or $\frac{1}{47}$ of the

* By this I do not mean water which is actually acid; for such water cannot be supposed to flow from the surface. All fresh water contains some carbonic acid, by means of which it is enabled to take up minute quantities of protoxide of iron. Bousingault and Levy—Journ. des Débats, Dec. 5, 1852—found that the air in the interstices of arable soil contained as much as 22 to 23 times as much carbonic acid as the atmosphere, and where the soil had been recently moistened, 245 times as much. Bones lying in such a soil would be dissolved in a comparatively short time.

† L'Institut. 1845, No. 593.

‡ Journ. für prakt. Chem. xviii, 501.

quantity of apatite that might be dissolved. At such a degree of dilution, proto-phosphate of iron undoubtedly remains dissolved in carbonated water. The Carlsbad water likewise shows that, by evaporating such a solution, phosphate of iron may be formed; for the peroxide of iron which Berzelius obtained in the analysis of that water, yielded phosphuret of iron when tested before the blowpipe.

The frequent occurrence of phosphate of magnesia in plants and animals, though in much smaller quantities than phosphate of lime, together with its very rare occurrence in minerals—magnesite, and magnesian apatite—induced me to make some experiments, with a view to ascertain whether phosphate of lime may be converted into phosphate of magnesia.* They were, however, unsuccessful; phosphate of ammonia and magnesia, cannot be formed, when carbonated water containing basic phosphate of lime is brought in contact with silicates of magnesia, and the ammonia generated by putrefaction. Since, however, phosphate of lime is decomposed by alkaline silicates and carbonates,† the resulting alkaline phosphates may give rise to the formation of phosphate of magnesia, by reaction with the magnesian salts.

It was natural to suppose that in the most frequent phosphatic mineral, apatite, minute quantities of magnesia might have escaped notice in the analyses hitherto made. I therefore examined apatite from Schlackenwald, Ehrenfriedersdorf, Estremadura, Arendal, the Laacher See, and from an erratic granite block, near Berlin, and found distinctly recognizable, though very minute, traces of magnesia in each specimen. The presence of magnesia in the phosphorite of Amberg was doubtful.‡

The frequent occurrence of phosphates in rocks, and as a consequence of it, their equally frequent occurrence in water, does away with the need for any hypothesis respecting the origin of apatite or other phosphates by fusion. Although it cannot always be demonstrated, what bases are combined with phosphoric acid in rocks or water, the researches hitherto made, justify the inference, that this acid is most frequently combined with lime. The water percolating through rocks, dissolves the minute quantity of phosphate which they may contain, and again deposits it in places where it stagnates and evaporates. There cannot indeed be any doubt that the small transparent crystals contained in the druses of

* German edition, i, 730.

† English edition, i, 923.

‡ German edition, i, 731.

phosphorite, are deposited from solution in water, that has percolated through this mineral, and dissolved the constituents of apatite. Chlorine and fluorine could not be detected in this phosphorite; but the water might have derived these substances from other rocks. The water of the Carlsbad springs, contains all the elements for the formation of apatite; and the very frequent observed presence of fluorine in water, justifies the conclusion, that these elements are in most instances present in water.*

The occurrence of apatite in granite, and other crystalline rocks, cannot be regarded as a proof that this mineral was formed by the agency of heat; for supposing that the granite were an igneous rock, it certainly did not come from the interior of the earth in the condition which it now presents. Its quartz could not have been separated from the mass in a state of fusion. But if the quartz, felspar, and mica in granite, have been formed by the action of water, the apatite that is sometimes found in granite, may equally have been formed in the same manner; and this is the more probable, because phosphate of lime is soluble in water, and because the apatite in sedimentary rocks, in fissures, and drusy cavities, cannot possibly have been formed by fusion.

With regard to the other phosphatic minerals, it is evident, from the circumstances of their occurrence, and from the fact that several of them contain water, that they cannot have been formed otherwise than from solution.

Phosphoric acid passes from minerals into plant organisms, and thence into the animal organism, where it accumulates largely, forming one of the chief constituents of bones. By the decay of organized substances, and of excretions, it again returns to the mineral state, and furnishes material for the formation of phosphates, such as vivianite, etc. The phosphates that are carried into the sea, undergo a similar cycle of alteration.†

The analyses of fossil remains of fish that have been collected by Bronn‡ show the presence of considerable quantities of phosphates of lime and magnesia. The bones and teeth of fish in the old Devonian sandstone, at the Burtneck Lake in Livonia, have not lost any considerable amount of their original constituents. The comparative researches made by Marcel de Serres, and L. Figuier,§ with fresh and recently petrified shells, and those of the older

* Sullivan—Phil. Mag. xxv, 229—found fluorine almost as frequent in rocks as phosphoric acid.

† German edition. i, 741, and 746—753.

‡ Geschichte der Natur. ii, 680.

§ Comptes rendus. 1846, xxii, 1050.

formations, show that the chemical alteration during petrefaction, consists chiefly in a diminution of the organic substance, complete removal of the phosphate, and increase of carbonate of lime, and peroxide of iron.

The phosphate of lime in the remains of marine animals buried in sedimentary strata is derived from the sea, and is gradually redissolved by meteoric water percolating through them. Bones that do not come in contact with water, will naturally remain unaltered as long as mineral substances under the same conditions.* It may, therefore, be easily understood that fossil bones in sedimentary strata sometimes contain more and sometimes less than the normal amount of phosphate of lime.

The same remark applies to the fossil bones of land animals. Thus Apjohn and Stokes found in the fossil bones of an extinct species of moose-deer, found in Ireland, 43·45 per cent. phosphates of lime and magnesia, with as much as 48·87 per cent. of organic substance. According to Lassaigne, the fossil teeth of the bear—*ursus spelæus*—and of the *anoplotherium*, contain phosphate of lime as the predominating constituent. On the contrary, Von Bibra† did not find a trace of phosphoric acid in fossil bones (probably mammalian) from the undermost stratum of the Keuper limestone of Schwebheim, at Schweinfurt. With the exception of 4 per cent. of lime, none of the original constituents remained; the principal ingredient was alumina, amounting to 63 per cent.

The skulls found in the Roman graves, situated in sand deposited by the Danube in the Raab district, are of remarkably large dimensions compared with the other parts of the skeletons. This has been found by Kindler‡ to be owing to the deposition of carbonate of lime in the interior of the skulls by the highly calcareous water of the Danube in such a way that the bones are separated from each other. Hydrochloric acid produces a much more copious disengagement of carbonic acid from these bones than from ordinary bones. A quantitative analysis, which would be very desirable, has not yet been made. The cinereal urns were likewise covered with a coating of carbonate of lime.

It is not merely the solid parts of animal remains in sedi-

* The whole surface of the Pampas, on the La Plata, seems to be a vast grave of animals of a former era. Darwin's Travels. German translation, i, 151.

† Journ. für prakt. Chemie. xii, 172.

‡ Poggendorff's Annal. lxxxvii, 611.

mentary strata that contain phosphate of lime in greater or less amount: all organic substances contain phosphates, and hence all sedimentary strata contain phosphate of lime even when they do not present any visible organic remains.

Forchhammer's* interesting analyses of the ashes of fungi point out an abundant source of phosphoric acid. The mean result of 15 analyses of fungi from various regions, from Greenland to the equator and Cape of Good Hope, give, as the percentage of phosphate of lime, 1.09. The occurrence of fungi in sedimentary strata, especially grauwacke, is much more frequent than was hitherto supposed, since it is only under very favourable circumstances that they retain their form, and since geologists devote but little attention to these plants. Strata which, though not containing any animal remains, ought probably to contain fungi, would therefore be very rich in phosphoric acid. Hence also the beneficial effects of putrifying fungi upon vegetation may be accounted for.

Phosphoric acid has been detected in the following sedimentary rocks:—in the chalk round Brighton, Schweitzer† found phosphate of lime: Henslow‡ speaks of nodules in the red chalk of the London clay and green sand, and from their shape regards them as coprolitic concretions of phosphate of lime. Sullivan§ found very minute traces of phosphoric acid in several specimens of carbonate of lime from the neighbourhood of Cork, and in muschelkalk and dolomite from Fulda (Hesse Cassel); in the roofing-slate used at Giessen, appreciable quantities, and in some instances the presence of wavellite was recognizable; in the flags from the west of Ireland, traces; in the old red sandstone of Cork, minute traces; in the slate of Corrigaline, near Cork, larger quantities. It is obvious that in manured soils phosphate of lime must be present.||

It has already been shown that most of the limestone strata of the secondary formation must have been deposited from the sea in a manner similar to that in which the coral islands and reefs have been formed by the agency of small marine animals, and that the remains of these animals are buried in the strata. Carbonate of lime is therefore accompanied by phosphates and organic substance, and hence the fertility of limestone soils.

* Journ. für prakt. Chemie. xxxvi, 385.

† L'Institut, 1843, No. 623.

‡ Ibid.

§ Journ. für prakt. Chemie. xxxvi, 250.

|| Richard Philips, Jun. Ibid., 19.

According to Silliman's* examination of calcareous corals their composition is

		Porites.	Madrepora.	Pocillopora.	Astrea.
Carbonate of lime	....	89·9—95·4	92·8—95·1	93·6—95·0	91·1—96·6
Phosphates and fluorides....		0·7— 2·1	0·5— 0·9	0·6— 1·5	0·3— 2·1
Organic substance	....	2·1— 9·4	4·3— 6·6	3·5— 5·6	3·2— 8·3

H. Rose's analyses† of rotatoria have given indisputable evidence of the presence of phosphate of lime in these animals.

There is, perhaps, no instance in which the influence of organized structures upon minerals is shown to a greater extent than in the circulation of phosphoric acid. Without a knowledge of these phenomena, the origin of most phosphatic minerals cannot be understood. Plants are the true collectors of this acid; they increase its quantity in uncultivated soil when the subsoil contains phosphates, or when these salts are supplied by water.

There can, in short, be no doubt that by far the greater portion of the phosphoric acid in phosphatic minerals occurring in sedimentary strata has circulated through the organism of plants and animals, and perhaps frequently. It seems, indeed, as if bones were susceptible of direct conversion into apatite; for Girardin and Preissner‡ state, that bones buried in the earth, and subjected to the influence of putrefaction, become converted into basic and neutral phosphates of lime, the latter crystallizing upon the surface, and in the interior of the bones, in small prisms, identical in form with apatite; and they regard this tendency to crystallize as the probable cause of the alteration.

CHAPTER XXIII.

CARBONATES.

The carbonated minerals comprise, besides neutral carbonates of the alkaline earths, neutral carbonates of the protoxides of iron, and of manganese, of the oxides of zinc, lead, and cobalt. They occur in a state of greater or less purity, or mixed together. Thus the carbonate of cobalt has hitherto been found only mixed in very small quantities—4 or 5 per cent.—with the carbonates of

* L'Institut. 1846, No. 674.

† Poggendorff's Annal. xxxii, 575. ;

‡ Comptes rendus. xv, 721.

lime and magnesia.* The carbonates of manganese and iron are invariably accompanied by small quantities of other neutral carbonates.

The carbonated minerals, with the exception of carbonate of lime, are characterized by a remarkable indifference to other acids; when dipped into concentrated nitric, or hydrochloric acid, they exhibit no effervescence, and it is only when they are powdered and heated with dilute acid, that solution is effected. On the contrary, the hydrated carbonates, prepared artificially, are all decomposed easily by acids.† It is sufficiently evident from this circumstance, and the fact that carbonated minerals are anhydrous, that the latter are not formed in the same manner as the artificial hydrated carbonates.‡

Carbonate of lime is the most abundant of the carbonated minerals; it exists in all sedimentary strata, and sometimes constitutes the principal part of mountain ranges. Next in frequency to carbonate of lime, is the carbonate of magnesia, in the form of dolomite. These two carbonates will be treated of in separate chapters, together with other rocks. In the present chapter, only the general characters of the carbonates of lime and magnesia, and of the double carbonate of these bases will be described, as well as the frequent displacement of the former by other substances.

A. *Carbonate of lime.*

According to a great number of experiments that I have made, carbonate of lime dissolves in about 1000 parts of water, saturated with carbonic acid.§ Fresenius|| states that it dissolves in 8834 parts of boiling water, and in 10,600 parts of cold water. I am unable to account for this remarkable difference.

Occurrence. Carbonate of lime is found more or less pure, both crystallized, perfectly, as in calc spar and arragonite; imperfectly, as in granular limestone, and in compact masses, as in common limestone, chulk, etc.

Formation. Carbonate of lime is one of those minerals that may be crystallized both by fusion and from solution. There can

* In the veins at Przibram, in Bohemia. Poggendorff's Annalen, lxxi, 564.

† H. Rose.—Pogg. Ann. lxxxiii, 421.

‡ Senarmont—Ann. de Chim. et de Phys. 3 Sér. xxx, 129—was the first who succeeded in obtaining these carbonates in the neutral and anhydrous state, by the combined action of pressure, heat, and excess of carbonic acid. The carbonates thus obtained resembled the native carbonates in their behaviour with acids.

§ German edition, i, 378.

|| Ann. der Chemie und Pharm. lix. 122.

be no doubt that in the greater number of instances, it is crystallized by fusion, and but rarely from solution. As an example of the crystallization by fusion, may be mentioned the observation made by Mitscherlich,* that pieces of limestone that had fallen into liquid lavas at Vesuvius, were converted into calc-spar; he also found a crystal of arragonite that had fallen from the sides of the crater into the liquid lava, and was converted into calc-spar. The rock in which it was situated, was not heated to fusion, but the arragonite had been so strongly heated, that its outer layer was converted into calc-spar, while the central mass still remained arragonite, and the crystalline form was unaltered, so that the action must have been very gradual.

It has already been shown that carbonate of lime is formed in the wet way by a variety of processes.† We are frequently able to ascertain which of these processes of formation has taken place.

Calc-spar in the form of other minerals. Carbonate of lime occurs pseudomorphous after gaylussite, anhydrite, gypsum spar,‡ baryta spar,§ and fluor-spar. By the separation of carbonate of soda and water, gaylussite is converted into an aggregate of minute calc-spar crystals, attached so as to present the appearance of a porous mass. This pseudomorph however is rare.|| Calc-spar, with the form of anhydrite, is described by Blum as occurring in the midst of a compact jasper.¶ This is a remarkable instance of the fact that water may penetrate the most compact minerals, and produce within them chemical alteration.

The carbonate of lime occurring upon the surface is rarely decomposed; but at more or less considerable depths, the decomposition by silica—quartz—and water, under the influence of heat,** certainly takes place, and when the temperature reaches ignition, the decomposition may take place without the presence of water.

Among the decompositions of carbonate of lime by the more powerful acids, that effected by sulphuric acid, originating from the oxidation of sulphuretted hydrogen, is the only one of geological importance.

Pseudomorphous minerals after calc-spar. Bitter spar, iron spar, manganese spar, zinc spar, malachite, quartz, prasem, silicious oxide of iron, chalcedony, cornelian, hornstone, opal, peroxide of

* Poggendorff's Analen. xxi, 157.

† English edition, i, 2 et seq. Nos. 1, 6, 4, 5, 7, 11, 12, 17, 19, 20.

‡ Ibid. 420. § Ibid. 434. || Blum Die Pseudomorphosen, p. 13.

¶ Zweiter Nachtrag zu den Pseudomorphosen, p. 18.

** English edition, i, 6, No. 3.

iron, göthite, brown hematite, iron pyrites—also in the form of arragonite, — white iron pyrites, pyrolusite, hausmanite, manganite, earthy cobalt, galena, silicious oxide of zinc, phrenite, compact felspar, chlorite, meerschäum. The fact that the substance of pseudomorphs is less soluble than the substance of the mineral whose form they present, is most clearly illustrated in the case of pseudomorphs after calc-spar; for all the substances above mentioned, are less soluble than carbonate of lime.

Carbonate of lime likewise occurs as the petrifying substance of organic remains, wood, &c.

B.—*Carbonate of magnesia.*

The solubility of carbonate of magnesia in water saturated with carbonic acid, was estimated by passing a current of the gas for twenty-four hours through water, in which the carbonate was suspended. Three experiments, corresponding closely, showed that it dissolved in 743 parts of such water, so that it is somewhat more soluble than carbonate of lime.

Occurrence. Carbonate of magnesia is seldom found crystallized, as magnesia spar, in chloritic and talcose slate, in serpentine and gypsum. Uncrystallized, it occurs in large masses in serpentine, and in clefts in dolerite. The quartzose magnesite will be noticed afterwards.*

It is a very remarkable fact, that carbonate of magnesia occurs as a mineral only in such small quantity, compared with the immense masses of carbonate of lime, while on the other hand, silicate of magnesia is so abundant, and silicate of lime comparatively so unfrequent. There can be no doubt that all limestone strata belonging to the secondary formations are deposits from the sea. The compact magnesite in serpentine, however, has not originated in this way; but has most probably been formed, together with the serpentine, by the decomposition of crystalline rocks. The analyses of river water,† show that carbonate of lime is carried into the sea in far larger quantity than carbonate of magnesia; consequently, the deposits of the former will be greater than those of the latter. The fact that there are no beds of compact magnesite in the secondary formation, shows that the same relation obtained during the period in which these rocks were deposited. On the contrary, the beds of dolomite, alternating with limestone, contain carbonate of magnesia as an essential constituent, and this leads to the inference that the carbonate of

* Chap. xxvi.

† English edition, i, 76, et. seq..

magnesia carried into the sea by rivers, contributes mainly to the formation of dolomite.

Formation. The carbonate of magnesia in the water of springs, proceeding from crystalline rocks that do not contain this carbonate, can only be formed by the decomposition of silicates of magnesia, by means of carbonic acid.* The association of opal with compact magnesite, in serpentine, affords strong evidence in favour of this mode of origin. Carbonate of magnesia may likewise be formed by other processes described previously,† and by the decomposition of chloride of magnesium by the organic action of plants.‡

When ordinary basic carbonate of magnesia is dissolved in water saturated with carbonic acid, and the solution, containing bicarbonate of magnesia, allowed to evaporate at the ordinary temperature, one half of the carbonic acid is given off together with water, and crystals of neutral carbonate of magnesia with three equivalents of water are deposited. G. Rose states that when the solution is evaporated at 212° F., crystals of anhydrous carbonate are formed; but that when the saturated solution is cooled nearly to zero, and the carbonic acid allowed to escape at this temperature, crystals of neutral carbonate, with five equivalents of water, are deposited.

Consequently water containing bicarbonate of magnesia would, by spontaneous evaporation, deposit neutral carbonate of magnesia with three equivalents of water. No mineral, however, is known that has this composition; but as the crystals readily loose their water in dry air, or when moderately warmed, becoming opaque, although without alteration of form, magnesite may be formed in this manner: when, for instance, water containing bicarbonate of magnesia flows slowly through a fissure and evaporates.

The other process by which anhydrous carbonate of magnesia is formed is the only one that can take place in hot springs. It must, however, be remarked that a continuous evaporation would very rarely take place, especially at Carlsbad.§ Carbonate of magnesia would probably be formed there if the water, after leaving the spring, flowed for some distance before entering a river; but this is not the case. At Ems, on the contrary, the conditions for the deposition of carbonate of magnesia appear to obtain, for the sinter from that place contains magnesia.||

* English edition, i, 2. No. 1. c.

† Ibid. 6, 7, 12.

‡ Ibid., 191.

§ Ibid. 148.

|| Ibid. 150.

It must also be borne in mind that the carbonate of magnesia forms, in combination with carbonate of soda, a double salt, which, though insoluble, does not separate from water for some days; and since these salts are generally associated in the water of hot springs, such as those of Carlsbad, it may be inferred that the deposition of carbonate of magnesia is prevented by the formation of double salts, more especially as this would be consistent with the rare occurrence of magnesite.

Magnesite spar has not yet been found with the form of any other mineral, but displacement pseudomorphs of this mineral by talc are known.* Carbonate of magnesia is not known as a petrifying substance.

C.—*Bitter-spar and Dolomite.*

Occurrence.—Bitter-spar is found in almost all granular varieties of dolomite, sometimes in fine crystals, in pores and drusy cavities; likewise in drusy cavities in other rocks, as granular and mountain limestone, variegated sandstone, cupreous slate, gypsum, basalt, doleritic amygdaloid, and the lava at Vesuvius. It occurs, however, most frequently in metalliferous veins traversing different rocks. Dolomite is very widely distributed, and is very often found alternating with sedimentary limestone.

Composition.—Bitter-spar and dolomite are double salts, consisting of the carbonates of lime and magnesia. Rammelsberg† remarks that the different carbonates in dolomite and bitter-spar may be present in very unequal quantities; but that in the pure varieties the quantities of lime and magnesia approximate to simple proportions.

There can be no doubt that the bitter-spar occurring in perfect crystals is a definite chemical compound of carbonate of lime with carbonate of magnesia. Nevertheless, we find that in the bitter-spar of different localities the relative proportion of the two carbonates varies considerably. It is, therefore, not necessary that they should combine definitely in order to form a distinct crystallized compound. As the two bases are isomorphous they may, within certain limits, be combined in very different proportions. Moreover, in many varieties of bitter-spar, carbonates of iron and manganese appear as representatives of carbonate of magnesia; and in this case definite equivalent proportions are still less to be expected.

* Chap. xli.

† Handwörterbuch des Chemischen Theils der Mineralogie. p. 96.

Rammelsberg gives three equivalent proportions, to which the composition of bitter-spar and dolomite approximates more or less:

I.				
Carbonate of lime	....	.		54.18
„ magnesia	....	1		45.82
				<hr/>
				100.00

Of this kind are—1, the bitter-spar of the Zillerthal, of Jena of Orenburg, and several other localities—2, the dolomite of la Spezzia, of Scheidama, of Mounts Ollioules and Cette in France, of the south coast of Capri, of the Valle di Sambuco, of Minari, of Vaage, in Norway, of Altenberg at Aix-la-Chapelle (compact dolomite), and thirty-six out of ninety-six specimens of dolomite analysed by Karsten*—3, the so-called rauchkalk in the districts of Ilfeld, of Suhl, and that from the zechstein strata between Beyenrode and the Mommel in the Thuringer Wald.

II.				
Carbonate of lime	....	3		63.95
„ magnesia	....	2		36.05
				<hr/>
				100.00

Consistent with this formula are—1, the bitter-spar of Koloruk, of Glücksbrunn, and a variety from the Zillerthal, &c.—2, the dolomite of Liebenstein, and of the coast between Vico and Sorrento—3, four among the ninety-six dolomites analysed by Karsten.

III.				
Carbonate of lime	....	2		70.28
„ magnesia	....	1		29.72
				<hr/>
				100.00

To this class belong—1, the crystallized bitter spar of Hall, in the Tyrol, and of the Taberg in Wermeland—2, amorphous gurhofian.

It will be seen that bitter-spar presents all three of these proportions; but that the composition of dolomite appears to be chiefly represented by the formula I, rarely by II, and never by III.

Karsten infers, from his numerous analyses of dolomite, that in those which are crystallized the carbonate of lime is always combined in simple equivalent proportion with another carbonate,

* Archiv. für Mineral, &c. xvii, 57, et seq.

which may be carbonate of magnesia alone, or together with carbonates of iron or manganese, and sometimes both. Some kinds of dolomite from Upper Silesia approximate in composition to three equivalents carbonate of lime, two equivalents carbonate of magnesia, and one equivalent carbonate of iron. This seems to be the maximum quantity of carbonate of iron. In the uncrystallized varieties of dolomite the diversity in the proportion of lime and magnesia is indefinite, but such masses must be regarded as mere mixtures of true dolomite and carbonate of lime.

It follows from the analytical results, that in all the specimens of dolomite whose composition approximates to the formula I, the carbonate of magnesia never amounts to 45·82 per cent., and that the carbonate of lime always exceeds 54·18 per cent.

Acids do not produce a perceptible effervescence with dolomite except when digested with it in fine powder. This shows that it is a true double salt, for if it were merely a mixture of the carbonates it should effervesce with acids in the same manner that the carbonates of lime or magnesia individually.* Dolomitic marl, and limestone generally effervesce with acids even when in large lumps. Karsten† found that dilute acetic acid extracts from them, at a temperature below 32° F., only carbonate of lime, while a dolomitic mass remains undissolved. Hence he regards them as mixtures of dolomite with unaltered carbonate of lime. This is the case with several limestones, especially those belonging to the zechstein and muschelkalk series.

Forchhammer‡ found from 0·371 to 1·02 per cent. of carbonate of magnesia in the chalk of Alindelille, near Ringstedt, in two other limestones, and in one from Clermont, which consists of small fresh water shells cemented together by insect larvæ. Most of the limestones formed by testacea or corals contain small quantities of carbonate of magnesia. Forchhammer found, by the analysis of a large number of corals, and of the shells of other marine animals, that the carbonate of magnesia amounts to about

* Bitter-spar presents the same character as dolomite, for it requires to be heated for several days with hydrochloric acid before it dissolves, while magnesite dissolves readily and with copious effervescence. Karsten—loc. cit., p. 58.

Klaproth and Walmstedt stated that magnesite dissolves only in hot acids; and, according to Berzelius, it may be treated with warm concentrated hydrochloric acid, even when powdered, without any remarkable evolution of carbonic acid. Stromeyer and Henry, on the contrary, dissolved it in cold acids. With regard to the decomposition of magnesite by acids, there appears to be some difference, the cause of which must be ascertained by further experiment.

† Archiv. für Mineral. &c. xxii, 572.

‡ Oversigt over det Kongelige Danske Videnskab. Forhandlingar. 1849 p. 89.

0·5 per cent. in the former; in *corallium nobile* it amounts to 2·1 per cent., and in *isis hippuris* to 6·4 per cent. In the bivalves it amounts to from 0·5 to 1·0 per cent.; in univalves to 0·2 or 0·5 per cent.; in cephalopoda to 0·1 or 0·4 per cent.; and in *annelidæ* from 1·3 to 7·6 per cent. With the exception of the *corallium* and *isis* families and *serpulæ*, therefore the carbonate of magnesia is generally under 1 per cent.; and it may be easily understood why limestone formed by these and similar animals contains the same proportion of carbonate of magnesia. If we take 2 per cent. as the quantity of carbonate of magnesia that may be present in limestone, without altering its character, we assume a limit which is defined by the action of marine animals which secrete carbonate of lime. The limestone formed by *serpulæ*, *corallium*, *isis*, and probably by other genera, ought, however, to be termed dolomitic limestone.

Forchhammer's numerous analyses of compact dolomite show that the carbonates of lime and magnesia do not present simple quantitative proportions in this rock, but that in the granular crystalline varieties they do. Nevertheless we cannot regard the former as a mere mixture, for it was found that the compact dolomite of Faxö in particular is a compound of the carbonates of lime and magnesia in simple equivalent proportions, together with carbonate of lime, pure or nearly so, for when acted upon by acetic acid, only a part (I) was dissolved, while a granular powder remained (II).

		I.	II.
Carbonate of lime	....	97·13	53·38
„ magnesia	....	2·87	41·42
		<hr/>	<hr/>
		100·00	100·00

The composition of the residue corresponds very nearly with simple equivalent proportions, and Forchhammer therefore considers it probable that compact dolomite is a mixture of carbonate of lime with a dolomitic compound of the two carbonates.

The formation of dolomite, and the numerous hypotheses put forward to account for it, will meet with special consideration in the succeeding volume.

Bitter-spar in the Forms of other Minerals.—Bitter-spar is met with very frequently in the form of calc-spar, especially in metaliferous veins, and in the drusy cavities of variegated sandstone, and of doleritic conglomerates, in agate nodules, &c. The alteration proceeds from the surface inwards, and the interior is either

hollow or contains a fragment of the original calc-spar.* The cavity in these pseudomorphs shows clearly that the carbonate of lime removed was greater in quantity than the carbonate of magnesia substituted for it.

At Schemnitz, in Hungary, and at Przibram,† bitter-spar occurs in the form of baryta spar; it probably occurs in the form of fluor-spar in Derbyshire,‡ and Breithaupt§ describes a pseudomorphous bitter-spar after anhydrite. These three pseudomorphs can only have been produced by displacement.

Iron spar, peroxide of iron, brown hematite, stilpnosiderite, iron pyrites, pyrolusite, quartz, chalcedony, steatite, blue carbonate of copper, and silicious oxide of zinc, occur in the form of bitter-spar. All these substances are less soluble than bitter-spar.

Bitter-spar is not known as a petrifying material.

D.—*Carbonates of Baryta and Strontia.*

According to my experiments, carbonate of baryta dissolves in 4300 parts of cold water, and in 2300 parts of boiling water.||

Occurrence.—Carbonate of baryta is not very abundant; it is found in metalliferous veins, in clay-slate, in mountain limestone, in the coal strata, in granite, and in felspathic porphyry.

Formation.—The presence of carbonate of baryta in the water of springs, its probable formation from silicates of baryta in minerals, and from sulphate of baryta, have already been treated of.¶ Breithaupt** mentions a rare instance of the conversion of heavy spar into witherite. As alkaline carbonates in solution decompose sulphate of baryta†† at a temperature of 77° or 81° F., this alteration may easily be accounted for, since water containing alkaline carbonates frequently has this temperature.

Crystallized carbonate of strontia occurs in metalliferous veins in gneiss, clay-slate, and micaceous schist. Its frequent occurrence, together with carbonate of lime, its formation and solubility, have already been treated of.‡‡

* Blum, *Die Pseudomorphosen*, p. 51.

† „ *Erster Nachtrag zu den Pseudomorphosen*, p. 92.

‡ Ibid.

§ *Paragenesis der Mineralien*, p. 202.

|| According to Fresenius, it dissolves in 14,137 parts of cold water and in 15,431 parts of boiling water.—*Annal. der Chemie.* lix, 122.—I am unable to account for this difference.

¶ English edition, i, 437.

** Loc. cit. p. 202.

†† English edition, i, 446.

‡‡ Ibid. 450, et seq.

E.—*Carbonate of Iron.*

The solubility of carbonate of iron in water, and in water saturated with carbonic acid, will be stated subsequently.

Occurrence.—Next to carbonate of lime and dolomite, carbonate of iron is one of the most abundant carbonated minerals. It occurs in perfect crystals, as iron-spar, in dykes and beds of the older rocks, and in sedimentary limestone. It occurs imperfectly crystallized, as sphærosiderite, in basalt and dolerite, &c.; and amorphous, as the compact sphærosiderite which forms considerable layers in the brown coal strata, in the coal strata, and in the lower green sand. Carbonate of iron is frequently accompanied by protoxide of manganese, amounting sometimes to 18 per cent.

Formation.—There can be no doubt that carbonate of iron has in the greater number of instances been formed by the decomposition of protosilicate of iron by means of carbonated water.* The formation of this mineral by other processes is certainly rare.†

There is some difficulty in accounting for the deposition of carbonate of iron, as its water solution so readily absorbs oxygen from the atmosphere, and deposits the iron as hydrated peroxide. It has, however, already been mentioned that there are several facts which prove the formation of this carbonate by deposition from ferruginous water.‡ The presence of organic substances in the water may have prevented the oxidation in many instances, and owing to the small solubility of carbonate of iron very minute quantities of organic substance, would suffice to produce this effect. Moreover, it must be remembered, that in a fissure communicating with the atmosphere, only at the upper end, intermixture of the air with that of the atmosphere would take place only to a limited extent, and the carbonic acid separated in the deposition of carbonate of iron might, from its greater density, accumulate in the fissure, and so far displace atmospheric air as to render oxidation impossible. The deposition of carbonate of iron in coal and brown-coal strata are more easily accounted for, since these strata contain such an abundance of organic remains.

Döbereiner and Glasson § state that iron-spar evolves carbonic oxide gas, together with carbonic acid, and I have found that basalt containing sphærosiderite also evolves the same gases.

* English edition, i, 3. No. 1. d. † Ibid. 12. ‡ Ibid. 156, et seq.

§ Annal. der Chemie. und Pharm. lxii, 87.

This disengagement of carbonic oxide might be expected from the presence of organic substance which was recognizable in this basalt, and if iron-spar contains organic substance, it is obvious that it would have prevented the oxidation of the carbonate of iron.

When water containing organic substance penetrates into rocks containing persilicate of iron, or hydrated peroxide of iron, originating from the earlier decomposition of the protosilicate, the peroxide of iron would be reduced to the state of protoxide, while the carbonic acid, formed at the same time, would combine with it.*

Carbonate of Iron in the Forms of other Minerals.—Carbonate of iron displaces calc-spar, bitter-spar, and heavy spar.

Blum† describes pseudomorphous iron-spar after calc-spar, occurring in drusy cavities in anamesite, in which also sphærosiderite is frequently met with. Fridolin Sandberger‡ also mentions such pseudomorphs. In the anamesite of Steinheim, near Hanau, arragonite and calc-spar are often found traversed by rays of sphærosiderite, coated with, or entirely converted into it.§

When water containing carbonate of iron penetrates a fissure

* English edition, i, 166.--Dr. C. Bischoff had an opportunity of making some observations as to the solubility of protoxide of iron in water saturated with carbonic acid, on the occasion of a search for an acidulous spring in the grauwanke of the Aarthal. Numerous specimens of water were taken as the boring increased in depth, and they exhibited a progressive increase in the amount of fixed substance. Very few of these specimens were clear; those which were turbid were filtered previous to analysis. The filtered water was invariably found to contain more iron than the clear water. One specimen, which contained a large quantity of suspended earthy substance, became clear after ten days, and this contained the largest amount of iron. Hence it follows, either that the brown-coloured particles held in suspension contained protoxide of iron which was dissolved by the carbonated water, or that, if the iron was only in the state of peroxide, it had been reduced by the organic substance which was found to be in the water. During the filtration of the most turbid water, it was observed that the clear filtrate soon became turbid again when exposed to the air, from the oxidation of protoxide of iron that had been dissolved. The clear water from the boring did not become turbid.

Analysis further showed that the permanently soluble constituents of this water increased with the depth in greater ratio than the earthy bicarbonates, thus affording an instance of the variation that the saline constituents of mineral water may experience at different parts of its course.

It is worth mentioning, that carbonated water and copious evolutions of carbonic acid, with a temperature of 73° F., at a depth of about 30 feet, are met with for several hundred yards round the boring. The detritus covering the clay-slate is coated to a considerable thickness with brown hematite. Here and there iron pyrites are also found. The whole phenomena here presented furnish a good illustration of the alternate solution and deposition of substances by carbonated water.

† Die Pseudomorphosen, p. 304; and Zweiter Nachtrag, p. 121.

‡ Ueber die Geognostischen Verhältnisse von Nassau, p. 102.

§ Theobald—Jahresbericht den Wetterauischen Gesellschaft. 1847 and 1850, p. 17.

or cavity in which calc-spar has been deposited, the carbonate of lime would be removed, and carbonate of iron deposited in its place; and even when the water contains carbonate of lime, together with carbonate of iron, the same change will take place; for part of the carbonic acid from the bicarbonate of iron is transferred to the carbonate of lime in the calc-spar, while the carbonate of iron is deposited. The density of iron-spar is 3.75, that of calc-spar only 2.69; consequently in the displacement of carbonate of lime by carbonate of iron, supposing the weights equal, the volume of the mass would be reduced and cavities formed. This is in accordance with the appearance of the pseudomorphous iron-spar above mentioned, which is either hollow or partly filled with calc-spar.

Iron spar forms an incrustation upon bitter-spar, consisting of a fine-grained aggregate of carbonate of iron. The surfaces of this pseudomorph are rough and uneven, the edges sharp, and the interior empty.*

In the Virtuous Lady Mine at Tavistock, in Devonshire, iron-spar occurs in the form of baryta-spar.† Breithaupt‡ also mentions similar displacement pseudomorphs.

The displacement of carbonate of lime by carbonate of iron is a phenomenon which appears to be of very considerable geological importance, for many beds of the latter may have originated in this manner.

Alteration of Iron-spar into Brown Hematite.—This alteration, occasioned by atmospheric oxidation, is recognizable in almost every locality where the latter mineral occurs. At the outcrop of veins, and other deposits of iron-spar, there is very often a complete and extensive conversion of one mineral into the other, while at greater depths the iron-spar is unaltered.§ Even

* Blum—loc. cit. p. 305.

† „ —Zweiter Nachtrag, p. 121.

‡ Paragenesis, p. 180.

§ The protection afforded by a thin coating was well illustrated by a precipitate of protoxide of iron, which I kept upwards of a year under water in an open vessel, after a thin layer of hydrated peroxide had been formed on the surface.

V. Leonhard—Jahrb. für Mineral. 1845, p. 14—directs attention to the formation of stalactites of hydrated peroxide of iron constantly going on in a mine near Cape Cornwall, that extends for some distance under the sea. After this mine had been closed for some years, it was found, on reopening it, that numerous stalactites had been formed, many of them eighteen inches long, and one inch in diameter. The stalagmites projecting from the ground had still greater dimensions. If, as is extremely probable, the water from which this deposition had taken place, contained carbonate of iron, iron-spar could not, under such circumstances, have been deposited.

freshly-worked iron-spar often undergoes such an alteration when exposed to the atmosphere. The alteration commences at the surface of the crystals. The light yellow colour of the iron-spar gradually passes into brown, and sometimes even black. The transparency is lost, but the lustre and cleavage are retained for some time. The brown hematite resulting from the perfect alteration of iron-spar is porous, because the carbonic acid separated amounts to more than the oxygen and water introduced, and there is a diminution of volume amounting to about $\frac{1}{3}$. More solid layers of brown hematite are often found in the direction of the cleavage planes, and it is here the change has commenced. Rosengarten* found in a specimen of iron-spar, partially converted into brown hematite, 11.3 per cent. peroxide of iron, 43.83 protoxide of iron, and 7.1 per cent. protoxide of manganese.

The alteration of iron spar into brown hematite, is so frequent, that it would be superfluous to mention localities. Sphærosiderite is also subject to conversion into brown hematite.

At Arzberg in the Fichtelgebirge, the pseudomorphs are found coated with pyrolusite, which probably originates from the manganese present in the iron-spar. At Siebenhitze on this mountain, they are quite covered with phosphate of copper. In the deposits of mercury ore at Morchel, the hollow or porous pseudomorphs contain very small crystals of blue carbonate of copper, with fibrous malachite, which seems to have been formed from copper pyrites, by means of the carbonic acid liberated from the iron-spar.† In the iron ore deposits at Hüllenburg and Lölling, in Carnithia,‡ chalcedony occurs in the upper parts, and sometimes forms a coating upon the pseudomorphs; but it never occurs with unaltered iron-spar, a proof that it was deposited from the water, by which the alteration of this mineral was effected. Nodules of solid white iron-spar likewise occur in the upper parts of the bed, surrounded by mica and covered with brown hematite. The brown hematite presents numerous clefts and drusy cavities containing water, which escapes from the larger pieces of ore, only after they have been exposed for some time on the surface.§

* Rammelsberg Handwörterbuch. 3^{tes} Supplem. p. 49.

† Blum; Die Pseudomorphosen, p. 20, et seq.; and Erster Nachtrag, p. 113.

‡ Morlat—Jahrbuch für Mineral. &c. 1847, p. 606.

§ Way—L'Institut., No. 563—shows that by treating iron-spar, that has been partially converted into brown hematite, with dilute hydrochloric acid, the hydrated peroxide of iron may be extracted, while the carbonate of iron remains in perfect white crystals. Even when the iron-spar contains carbonate of lime, it remains with the carbonate of iron, in the form of a double carbonate.

Sismonda* is of opinion that in the alteration of carbonate of iron into hydrated peroxide of iron, at Traversella, the iron pyrites mixed with it has played an important part, but his view is certainly incorrect; the decomposition of the iron pyrites is merely a collateral phenomenon.

Ankerite is sometimes converted into brown hematite; its greyish or red colour passes into brown, the surfaces of the crystals and masses assume a porous character, and at last there remains only a skeleton as it were, of hydrated peroxide of iron.† This pseudomorph is found in the iron-spar bed in Styria, and in the Rathhausberg, near Gastein. According to Lander,‡ the ankerite of the Erzberg in Styria, contains 49·61 per cent, of protoxide of iron, and according to Fritsche,§ the pistomecite of Thurnberg in the Salzberg Alps, contains 33·92 per cent. protoxide of iron. This ankerite would therefore yield from $\frac{1}{3}$ to $\frac{1}{2}$ of hydrated peroxide of iron, after the removal of the carbonate of magnesia, and, in the former mineral, of the carbonate of lime.

Alteration of iron-spar into red hematite. This alteration is not nearly so frequent as the last. There is a remarkable instance of it at Bresoir in Alsace. The change commences at the surface, and progresses inwards. The pseudomorphs of Presnitz in Bohemia, are either porous, or filled up with soft red iron ochre. In these also there were very thin hard layers in the direction of the cleavage planes, passing through the crystals, or extending through the hollow pseudomorphs from one surface to another. The pseudomorphs of Jedvonnitz in Moravia, are sometimes porous, at others filled with red iron ochre, so that the form of the iron-spar is retained by a crust of compact red hematite.|| The porous character of these pseudomorphs is explained by the contraction that takes place, amounting to nearly one half.

Haidinger considers that the direct conversion of iron-spar into red hematite, is questionable in many instances; and in others, he regards it as undetermined. However, I am of opinion that the direct conversion of iron-spar into red hematite is very improbable. The red iron ochre present in the interior of the pseudomorphs, is doubtless the remains of the hydrated peroxide of iron that was not converted into peroxide, for notwithstanding its red colour, it probably contains water, as is the case with the red

* Jahrb. für Mineral, &c. 1835, p. 194.]

† Poggendorff's Annalen. xi, 190.

‡ Rammelsberg Handwörterbuch. 2^{tes} Suppl. p. 87.

§ Poggendorff's Annalen. lx, 147.

|| Die Pseudomorphosen, p. 188; and Erster Nachtrag, p. 110.

oxide of iron, precipitated by an alkali from a boiling solution of persalts of iron. The interior of the pseudomorphs at Stehen, is coated with brown iron ochre, and in this instance, the presence of hydrated peroxide of iron cannot be doubted. But if this were a product of the alteration of red hematite, the change would probably have commenced at the surface, and not in the interior. The actual conversion of hydrated peroxide of iron, into peroxide, is however proved by the pseudomorphous red hematite after brown hematite.

Certain kinds of brown iron ochres, as in the Gulsen at Kraubet, present admixtures of magnetic iron ore; they are highly magnetic, owing to the presence of this substance, which is recognizable as isolated grains in the mass. This magnetic iron appears to have been formed by a partial oxidation of the carbonate of iron, and this view is supported by the circumstance, that peroxide of iron expels carbonic acid from carbonate of iron in the wet way,* so that the peroxide of iron formed by the partial oxidation of the carbonate of iron, combines with the remaining protoxide, and in this way the formation of magnetic iron ore from carbonate of iron may be accounted for.

Alteration of iron-spar into kakorenite.† This mineral is found at Antwerp, in the state of New York. Its formation appears to have been preceded by alteration of the iron-spar into hydrated peroxide of iron. Now as phosphate of lime dissolved in carbonated water, decomposes bicarbonate of iron,‡ the alteration in question may be accounted for in this way.

Quartz and hornstone in the form of iron-spar. These pseudomorphs show that silica displaces carbonate of iron. As sphærosiderite dissolves in 1646 parts of water,§ saturated with carbonic acid, it is much more soluble than the soluble modification of silica, and consequently its displacement by the latter substance is in accordance with the general rule.

Carbonate of iron occurs, according to Zippe,|| at the Postelberg in Bohemia, in the brown coal strata, as a petrifying substance.

F.—Carbonate of manganese.

Occurrence. Carbonate of manganese is found crystallised, as

* H. Rose—Poggendorff's Annalen. lxxxiii, 135.

† Hydrated phosphate of peroxide of iron.

‡ English edition, i, 13, No. 20.

§ German edition, i, 388.

|| Blum—Zweiter Nachtrag. p. 207.

manganese-spar: compact, as rhodochrosite, in metalliferous veins, and in beds of red hematite.

Manganese-spar is very rarely pure, it contains varying quantities of the isomorphous carbonates of iron, lime, and magnesia. This is owing to the circumstance that carbonate of manganese occurs in water in very small quantity, together with these carbonates.

With regard to the formation and alteration of manganese-spar, the same relations obtain as in the case of iron spar.

Displacement of calc-spar by carbonate of manganese. Blum* describes a specimen of pseudomorphous carbonate of manganese, after calc-spar, from metalliferous veins in the porphyry at Nagyag in Transylvania, consisting of very small crystals of carbonate of manganese. Most of these pseudomorphs are more or less hollow.

Although carbonate of manganese is very readily decomposed by oxygen, the higher oxides of manganese have not yet been met with in the form of manganese-spar.

The remaining carbonates of the metals will be treated of in the succeeding volume, under the head of metalliferous veins.

CHAPTER XXIV.

CHEMICAL REACTIONS RELATING TO THE ALTERATION OF MINERALS.

IN the first volume of this work I have described a number of chemical reactions relating to the alteration of minerals, and I will in this chapter add some further details that have been ascertained since that time.

34. I have already shown† that alkaline carbonates and silicates may exist together in solution. The experiments have since been extended in order to ascertain whether alkaline silicates may exist in such a solution, saturated with free carbonic acid. As I found that chloride of ammonium precipitated gelatinous silica from a very dilute solution of alkaline silicate, silicate of soda was added to water, saturated with carbonic acid, until a slight alkaline reaction was produced. Chloride of ammonium did not render the liquid turbid for some hours. This, however,

* Zweiter Nachtrag, p. 76.

† English edition, i, 2.

was not sufficient to indicate with certainty that there was undecomposed silicate of soda in the liquid. It did not appear desirable to evaporate to dryness by heat, and analyse the residue, because carbonate of soda would be decomposed by the free and still dissolved silica and silicate of soda reproduced.* For this reason, a dilute solution of silicate of soda, saturated with carbonic acid, was evaporated at the ordinary temperature over sulphuric acid in an air-pump. On exhausting the air, free carbonic acid escaped in considerable quantity, and after fourteen days there remained a firm gelatinous mass, which effervesced copiously with acids. This residue was thoroughly washed with water until the filtrate did not present any alkaline reaction. The first portion of the filtrate gave, with chloride of ammonium, transparent gelatinous flocks, indicative of the presence of undecomposed silicate of soda. The washed residue was dried and again washed, by which means it was slightly reduced in weight: by treatment with hydrofluoric acid a slight residue, containing soda, was left.

The filtrate from the gelatinous precipitate was again evaporated to a small volume under the air-pump, and meanwhile silica separated in flocks, though the quantity was too small to test for soda. Carbonic acid was separated from the filtrate by means of hydrochloric acid, and the quantity carefully estimated. After evaporating this liquid to dryness, and again dissolving the chloride of sodium, some more silica was separated.

The per centage amount of the substances obtained in the previous experiment was

<i>a</i> Silica by first evaporation	....	....	....	53·21
<i>b</i> Soda, combined with <i>a</i>	....	....	....	0·63
<i>c</i> Silica, by second evaporation	....	....	....	2·42
<i>d</i> Carbonate of soda	....	....	....	37·11
<i>d</i> Silica obtained with the chloride of sodium			....	0·93
<i>e</i> Soda, combined with <i>d</i>	....	....	....	5·68
				<hr/> 100·00

This experiment shows that in water, saturated with carbonic acid, silicate of soda may exist with carbonate of soda in the proportion of 6·63 to 37·11. Water of this kind might consequently produce three different changes in minerals with which it came in contact:

1. Decomposition of silicates by the free carbonic acid; for instance, the conversion of silicate of lime into carbonate of lime.

* English edition, i, 7.

2. Decomposition of silicates by the alkaline carbonates; for instance, the conversion of silicate of lime into carbonate of lime, while the silica combines with the alkali.

3. Conversion of silicate of soda into silicate of potash* when the water contains carbonate of potash.

If the silicate of potash thus produced, together with that already existing in the water, were introduced into the mineral, the quantity would exceed that of the silicate of soda decomposed.

Since the occurrence of water saturated with carbonic acid is rare, in most instances the water filtering through rocks would not contain so large an amount of alkaline carbonates in proportion to the alkaline silicates, as was found in the experiment just mentioned; but, on the contrary, the latter would predominate.

The composition of the portion separated by the first evaporation is given under A; that of the portion remaining in solution after the second evaporation under B

		A.	B.	C.
Silica	....	98.83	14.33	66.04
Soda	....	1.17	85.67	33.96
		<hr/> 100.00	<hr/> 100.00	<hr/> 100.00

Therefore A would be an acid, B a basic compound, if they can be regarded as definite compounds. However this may be, it is certain that a silicate of soda having the composition C is decomposed during the evaporation of a dilute solution in water into two parts, the one containing a large excess of silica, while the other contains a large excess of soda, and the former amounting to eight times the latter. It follows, from these results, that in the combination of silica with bases, the relative proportions may vary very much.

There can be no doubt that by the evaporation of very dilute solutions of alkaline silicates, filtering through rocks, decomposition is effected similar to that above mentioned, for the evaporation would take place at the ordinary temperature, and even more slowly than in the air-pump. It is improbable that the free carbonic acid in water would take any part in this decomposition, which commences only when the evaporation has proceeded to some considerable extent, and meanwhile the free carbonic acid is separated; in my experiments it was separated at once, when the air was exhausted.

* No. 38, p. 65.

It may be inferred that when water exercises a decomposing and solvent action upon minerals, silicates with excess of acid, and others with excess of base, are formed, the more soluble product being removed while the less soluble product is left. Hence it is intelligible that the alteration of the composition of minerals exposed to such influences should be very gradual, and in the first stages scarcely recognizable by either mineralogical or chemical means.

Lastly, the above experiment shows that water containing carbonic acid, with alkaline carbonates and silicates, may deposit siliceous substances with very minute admixtures of the bases.* Such substances actually occur; for instance, opal, flint, cachelongite, &c., contain minute quantities of alkalies and other bases. Probably these bases would be found in other siliceous substances by careful analysis. On account of the sparing solubility of earthy silicates there is no means of ascertaining by experiment whether they may be decomposed in a similar manner; but there is scarcely any doubt that such is the case. It might be supposed that the very sparingly soluble silicate of magnesia has contributed to the formation of opal for almost every specimen of this mineral contains magnesia.

At the same time that acid silicates are deposited in fissures and drusy cavities from water containing silicates; basic silicates would be carried away in solution, and they are actually met with in the water of springs, analysis showing that in all instances the quantity of silica is very small compared with that of the bases. It is true that only small portions of these bases can be regarded as combined with silica, and that the larger portion is combined with other acids and halogens; but hitherto the carbonic acid of the carbonates has rarely been estimated directly, and thence the composition of the silicates ascertained.† It is, however, highly probably that basic salts would be found to exist in the water of springs if sufficient care were exercised in the execution of these difficult analyses.

35. Silicates of zinc, copper, nickel, and silver, are decomposed by carbonic acid.

a. When carbonic acid was passed for twenty-four hours through water, in which, artificially prepared silicate of zinc was suspended, decomposition took place, and when the operation was continued for three days with finely powdered native silicate of

* Chap. xlii.

† English edition, i, 5.

zinc, more than one half of it was converted into carbonate of zinc.*

b. Artificially prepared, and native silicate of copper, are very differently affected by carbonic acid. The gas was passed for eight days through water, in which the following silicates were suspended.

	Proportion of water required for solution of the residue.	Composition of the residue.	
		Silica.	Oxide of copper.
Silicate of copper (<i>prepared artificially</i>)	} 9948	0.49	0.51
Silicate of copper (<i>from Tagilsk</i>)	} 18089	0.49†	0.51
Diopase ....	.... 75308	0.17‡	0.83

These remarkable differences in the quantity of substance dissolved, and in the time requisite for the solution, can only be owing to the differences in the state of aggregation, and to modifications in the silicates of copper employed. The artificial precipitated silicate of copper, in a state of very fine division, was employed moist, and was the most soluble: the silicate of copper and diopase were, on the contrary, in the least soluble state. Silicate of copper is amorphous; diopase is crystalline, and hence the difference in their solubility, and the time required for solution. As both of these silicates are easily decomposed by the stronger acids, it is evident that this decomposition cannot be taken as a measure of the decomposition by carbonic acid. This involves long periods of time, as in the case of all decomposition effected by this substance, which plays so important a part in mineral alteration. The decomposition of diopase, however, shows that no rock containing bases, capable of combining with carbonic acid, would be capable of resisting the continued action of this agent.

The substance dissolved by the carbonated water, is, in these three experiments, undoubtedly a mixture of carbonate of copper and silica; for the quantity of the latter does not, by a long way, amount to the maximum of silica found in the water of springs,‡ even in that, from the artificial silicate of copper.

c. When carbonic acid was passed for three days through water, in which artificially prepared silicate of nickel was suspended, there remained after the evaporation of the liquid, a pale green residue, which, when mixed with hydrochloric acid,

* German edition, ii, 1882.

† The silica contained some oxide of iron.

‡ German edition, p. 1886.

effervesced only when heated. The dissolved substance amounted to $\frac{1}{10\frac{1}{2}}\frac{1}{25}$ of the carbonated water, and consisted of:*

Silica ....	....	....	0.37
Oxide of nickel ....	....	....	0.63
			<hr/> 1.00

d. Silicate of silver mixed with water, and exposed for forty-eight hours to the action of carbonic acid, gave a somewhat blackish solution, which filtered perfectly clear, and when evaporated at a gentle heat, left a dark brownish residue, that effervesced copiously with nitric acid. When no more gas was generated, the liquid was warmed, and the evolution of gas commenced again. Assuming that the decomposed silicate was dissolved as neutral carbonate, the composition of the residue would be:†

Silica ....	....	....	0.12
Carbonate of silver	....	....	0.88
			<hr/> 1.00

This was dissolved in 5116 parts of carbonated water. It cannot be determined whether or not the silica was combined with a part of the oxide of silver, although the latter is more probable, and in that case, the decomposition of the silicate of silver would have been complete.

36. Sulphuretted hydrogen decomposes the silicates of zinc and lead, suspended in water; sulphides of the metals are formed, and silica is separated. The silicates of copper, nickel, and silver, are in like manner decomposed by sulphuretted hydrogen, but they are dissolved by sulphuretted hydrogen, and are not deposited for some time.

a. When sulphuretted hydrogen was passed through water, in which silicate of zinc was suspended, a flesh coloured precipitate was formed. This precipitate was washed, and after drying in the air, contracted into small fragments, containing an opaline nucleus, surrounded by a brownish crust, which, when mixed with dilute sulphuric acid, evolved sulphuretted hydrogen. Silicate of zinc is therefore decomposed by sulphuretted hydrogen, with formation of sulphide of zinc and silica, which separate from each other in drying.

* German edition, p. 1891.

† There would seem to be an energetic combination of the oxide of silver with carbonic acid, for the whole of the silver is separated only by digesting the residue with nitric acid.

b. Artificially prepared silicate of copper, suspended in water, is immediately turned brown by sulphuretted hydrogen. When the green colour had entirely disappeared, the liquid was filtered the filtrate was brown and opaque, or slightly translucent in thinner masses. The residue separated by filtration, was dark green, when dried, and presented small, irregular white particles of silica. A portion of the filtrate left for some days in an open vessel, until the smell of sulphuretted hydrogen disappeared, deposited blackish green flocks, became transparent, and when filtered, colorless. The same result was produced by evaporating the filtrate in the sun during twenty-four hours. By evaporating a larger quantity of the liquid to dryness, a dirty white residue was obtained, consisting of silica, and sulphide of copper. When the free sulphuretted hydrogen was separated by acetate of lead, the liquid filtered quite clear. It is evident therefore, that silicate of copper is soluble to some extent in sulphuretted hydrogen water.

When the dark green sediment, that separated from the brown solution by sulphuretted hydrogen, was treated with nitric acid, white silica remained. When examined by means of a magnifying glass, the sulphide of copper was found not to be intimately mixed with the silica, which had separated in small particles.

Silicate of copper from Tagilsk was finely powdered, suspended in water, and exposed to a current of sulphuretted hydrogen, until the green colour had disappeared. The liquid presented the same characters as that obtained with the artificial silicate. It was quite as dark coloured, and after being heated to the boiling point, the filtrate obtained was much darker green than in the case of the artificial silicate, and after some time, deposited a dark green sediment. Ammonia did not produce a blue colour in this solution. The reaction of ferrocyanide of potassium could not be observed, on account of the dark colour of the liquid. A dark green residue remained upon the filter, somewhat less than in the case of artificial silicate of copper.

It is remarkable that the dark brown liquid obtained by treating silicate of copper with sulphuretted hydrogen, is not wholly decolorized when boiled for some minutes, although by exposure for twenty-four hours in an open vessel, to the heat of the sun, it becomes quite colorless, and the dissolved substance is entirely deposited. The same result was produced when the liquid was allowed to stand for about two weeks in an open vessel at the ordinary temperature. In this way a blackish green preci-

pitrate was formed. The liquid did not give any reaction with ferrocyanide of potassium, and the smell of sulphuretted hydrogen had quite disappeared. It seems, therefore, that the sulphuretted hydrogen was not entirely separated by boiling for a short time, although it was by exposure for a long time at the ordinary temperature. In the latter case, however, a very sensible quantity of sulphuric acid was formed.

A large piece of silicate of copper immersed in water, saturated with sulphuretted hydrogen, in a close vessel, became quite black; and on the following day, the liquid was turbid. After fourteen days, numerous white flocks were floating in the liquid, which still smelt of sulphuretted hydrogen. In this instance, a part of the silicate of copper had been decomposed, the silica liberated was partially dissolved, and partly suspended or deposited.

Diopase, finely powdered, and suspended in water, is acted upon by sulphuretted hydrogen in the same manner as powdered silicate of copper. Crystals of diopase were not blackened, and after being immersed fourteen days in sulphuretted hydrogen water, retained their fine green colour and lustre; but a very thin layer of a white powder was deposited upon the bottom and edge of the glass, so that there was a separation of silica, but singularly enough, there was no sensible formation of sulphide of copper. In order to increase the action, sulphuretted hydrogen was passed through the liquid, and the vessel closed. At the end of five days, or nineteen days from the commencement of the experiment, the crystals of diopase had become black at some points, and after forty-two days, they were reduced to a coarse black powder; in some of the larger fragments, green spots could be detected here and there.

Therefore silicate of copper, whether artificial or native, powdered or in mass, amorphous or crystalline, is decomposed by sulphuretted hydrogen; but there is a great difference in the time required for the decomposition of amorphous silicate of copper, and for that of crystals of diopase respectively.*

c. Artificially prepared silicate of nickel, suspended in water, through which a current of sulphuretted hydrogen was passed, was soon decomposed, and yielded black flocks. When the silicate was allowed to remain for twelve hours in contact with the sulphuretted hydrogen water, the whole of it became black. The liquid did not become clear, but remained milky: it was rendered somewhat clearer by filtration, but still retained a brown

* German edition. ii, 1895, et seq.

colour. When kept for some weeks in closed vessels it did not become clear, but turned darker, owing to a further decomposition of silicate of nickel by the remaining sulphuretted hydrogen. The filtered liquid was brown and milky.

d. Artificially prepared silicate of silver, suspended in water through which sulphuretted hydrogen was passed, gave, like the above-mentioned silicates, a dark-brown liquid, which became rather milky when poured out. When boiled until the smell of sulphuretted hydrogen disappeared, the filtered liquid was still somewhat brownish. Nitric acid decomposed the liquid at the ordinary temperature, and the filtrate was then clear, but soon became milky again.

e. Artificially prepared silicate of lead was blackened by sulphuretted hydrogen and decomposed, as is probably the case with all metallic silicates; but although the sulphuretted hydrogen was in large excess, the filtrate was perfectly colorless, so that silicate of lead is not dissolved by sulphuretted hydrogen water.

37. Sulphuretted hydrogen decomposes the carbonates of copper, lead, and silver, when suspended in water, and even the carbonates of those metals that are not precipitated by it from solutions of their saline compounds with the stronger acids; for instance, the carbonates of iron, manganese, zinc, nickel, and cobalt.

38. Silicate of soda is decomposed by carbonate of potash, with formation of silicate of potash and carbonate of soda. When a solution of monosilicate of soda was mixed with solution of carbonate of potash, the liquid evaporated to dryness, and the residue mixed with alcohol, no alkaline carbonate was dissolved, but a portion of the alkali was extracted from the silicate, while acid silicate remained. When the alcoholic filtrate was evaporated to dryness, the residue neutralized with hydrochloric acid and chloride of platinum added, the double chloride of potassium and platinum was precipitated, showing that the carbonate of potash had decomposed the silicate of soda.

The residue left by the alcohol, consisting of alkaline carbonates and silicates, did not give a clear solution in water, showing that an acid silicate had been formed.

39. Solutions of alkaline silicates extract minute quantities of alumina from silicate of alumina. When silicate of soda—calculated as anhydrous—dissolved in 11.5 times its weight of water, was digested at a gentle heat with artificially prepared hydrated silicate of alumina, evaporated to dryness and the residue washed thoroughly with cold water, the liquid was found to contain 0.55

alumina for 100 silicate of soda. If this alumina was dissolved as silicate, the amount would be 2·0; but this was not ascertained.

When an indefinite quantity of silicate of alumina was mixed with a solution of a much larger quantity of silicate of potash, and the liquid evaporated to dryness, the residue dissolved perfectly in water. This result induced me to make the experiment quantitatively: 100 parts of silicate of potash dissolved in 3·4 times its weight of water, mixed with 16 parts silicate of alumina—both silicates calculated as anhydrous—gave a perfect solution by the aid of a gentle heat. When, however, water was added, silicate of alumina was separated, and was not dissolved again when the liquid was boiled for a long time. The residue was then thoroughly washed with cold water, and the liquid was found to contain 0·62 alumina.

This second experiment shows that more silicate of alumina is dissolved by a warm concentrated solution of silicate of potash, than by a cold dilute solution.

When silicate of alumina was digested for four days with a solution of silicate of soda at the ordinary temperature, no alumina could be found in the filtered liquid, but the residue was found to contain a trace of soda, possibly, however, owing to the imperfect washing.

It can hardly be supposed that a decomposition which, at a moderate temperature and by evaporation to dryness, is so decidedly recognizable, should not take place at all at the ordinary temperature and when the liquid is not evaporated; and it must be remembered that ammonia, by which alumina was tested for in the last experiment, does not indicate the presence of very minute traces of alumina.

Solution of carbonate of potash does not dissolve a trace of silicate of alumina, even at the boiling temperature; so that the alkaline carbonates dissolved in water cannot exercise the same action as alkaline silicates.

Solution of silicate of soda dissolves a sensible quantity of hydrated alumina, even at the ordinary temperature, after some long time. When this solution was evaporated to dryness at a very gentle heat, there remained some stellar groups of very thin prismatic crystals.

40. Silicate of lime is decomposed by sulphate of magnesia with formation of silicate of magnesia and sulphate of lime. This reaction is very evident when silicate of lime, dissolved in boiling water, is mixed with a concentrated solution of sulphate of mag-

nesia; the liquid soon becomes turbid, and after some time silicate of magnesia is precipitated in white flocks. A cold solution does not become turbid, although silicate of magnesia is less soluble than silicate of lime. Since, however, both of these silicates require, under different circumstances, very different quantities of water for solution,* the solution might contain the minimum of silicate of lime, which does not differ much from the maximum quantity of silicate of magnesia. Moreover, the silicates are all much more soluble "*in statu nascenti*" than otherwise. It is, therefore, possible that in this experiment there was a sufficient amount of water for the solution of the silicate of magnesia formed by the mutual decomposition of silicate of lime and sulphate of magnesia.

In order to avoid error in this experiment, it is necessary to make sure of the purity of the silicate of lime. It was prepared by precipitating chloride of calcium with an excess of silicate of soda, and thoroughly washing the precipitate until it had considerably diminished, so that I could be sure that both the soluble salts—the excess of silicate of soda and the chloride of sodium resulting from the reaction—were perfectly separated. The silicate of lime thus prepared, when dissolved in water, has an alkaline reaction upon litmus paper.

41. Silicate of lime is likewise decomposed by chloride of magnesium, with formation of silicate of magnesia and chloride of calcium. The reaction may be observed in the same manner as that last mentioned. However, the liquid does not become turbid for some time, and it is only after some days that a precipitate is formed.

A solution of silicate of lime in boiling water did not, by standing for the same length of time, become the least turbid, showing that the precipitates produced by sulphate of magnesia and by chloride of magnesium could not be anything but silicate of magnesia. The fact that the precipitation by chloride of magnesium was much less than that produced by sulphate of magnesia, may have been owing to the alteration of the silicate of lime, which had been exposed for some days before the latter experiment, and had become dry.

42. Silicate of iron is not decomposed by sulphate of magnesia or by chloride of magnesium. The silicate of iron was prepared by precipitation from a solution of chloride of iron by an excess of silicate of soda, the precipitate washed until the

* Chap. xxvi.

filtrate gave no further reaction with nitrate of silver. When this silicate was digested for twenty-four hours, at a gentle heat, with solutions of sulphate of magnesia and of chloride of magnesium, not a trace of iron could be detected in the filtered liquids.

These experiments likewise show the very minute degree of solubility of silicate of iron.

43. Silicate of alumina is decomposed by chloride of calcium and by sulphate of lime, with formation of silicate of lime and sulphate of alumina, or chloride of aluminum. When artificially prepared silicate of alumina was digested at a gentle heat with a solution of chloride of calcium, the filtered liquid was rendered turbid by ammonia, and a precipitate of alumina was soon formed. When the residue was washed, digested with hydrochloric acid, and the alumina precipitated by ammonia, oxalate of ammonia gave a considerable precipitate of oxalate of lime, showing that the silicate of alumina had been decomposed by the chloride of calcium.

Silicate of lime was likewise formed when silicate of alumina was digested with a solution of sulphate of lime.

Similar experiments were made with native silicate of alumina—clay from the brown-coal strata—carefully washed beforehand. The results, after several repetitions, were as follows:—

	I.	II.	III.	IV.
Alumina (<i>in solution</i>)	Abundant precipitate.	Rather less than in I.	Rather less than in II.	Traces.
Lime (<i>in residue</i>)	Abundant precipitate.	Rather less than in I.		

I. Silicate of alumina was digested with sulphate of lime solution for one hour.

II. Silicate of alumina was digested with chloride of calcium solution; after forty-eight hours the liquid was filtered and tested.

III. Clay digested with chloride of calcium solution.

IV. Clay digested with sulphate of lime solution.

Hence it would appear that silicate of alumina is decomposed by sulphate of lime in larger quantity than by chloride of calcium, and that clay is decomposed in larger quantity by chloride of calcium than by sulphate of lime. However, no great weight can be laid upon these differences, as the experiments were not quantitative; but it is at least certain that artificial silicate of alumina is decomposed more readily and in larger quantity than

the native silicate. This is in conformity with the general character of the silicates, that the older they are the less soluble and decomposable they are. A long continued action of lime-salts upon silicate of lime did not appear to produce any greater degree of decomposition. The experiment II gave to all appearance the same result after the silicate and chloride had been digested for only two hours.*

44. Silicate of alumina is decomposed by chloride of magnesium, or by sulphate of magnesia, silicate of magnesia being formed together with chloride of aluminum or sulphate of alumina. The experiments were made in the same manner as those with the lime-salts, and the results were:—

	I.	II.	III.	IV.
Alumina (in solution)	Tolerably abundant precipitate.	Almost the same.	Much less than in I.	Traces.
Magnesia (in residue)	Abundant precipitate.	Much less than in I.		

I. Silicate of alumina digested for one hour with chloride of magnesium.

II. Silicate of alumina digested for two hours with sulphate of magnesia.

III. Clay digested with chloride of magnesium.

IV. Clay digested with sulphate of magnesia for forty-eight hours.

The decomposition of silicate of alumina by chloride of magnesium is therefore unquestionable.

45. Carbonate of lime decomposes chloride of aluminum; alumina is precipitated, carbonic acid evolved, and chloride of calcium remains in solution.†

It was to be expected that a solution of bicarbonate of lime would produce the same precipitation. This may be observed by hanging a crystal of alum in the solution, when bubbles of gas immediately rise from the edges and angles of the crystal, while the liquid below it becomes turbid from the precipitation of alumina. As the sulphate of lime produced, requires for solution barely half as much water as the bicarbonate of lime, it remains dissolved.

46. Bicarbonate of magnesia is decomposed by silicate of potash, silicate of magnesia and carbonate of potash being formed.

* See German edition, ii, 2160, et seq.

† Fuchs.—Jahrbuch für Chemie, lxii, 100,

Saturated solutions of bicarbonate of magnesia and of silica in potash mixed together became slightly turbid after a while, but no deposit was formed. On this account I added some alcohol; and, as I expected, the silica which might have been precipitated by this substance, owing to the decomposition of silicate of potash, was precipitated in the state of silicate of magnesia, showing that this compound had been formed. The white flocculent precipitate was collected by filtration, washed with water, and dried at 212° F. When moderately heated, water was separated; but this was not estimated directly for fear of losing any carbonic acid from carbonate of magnesia that might be present. On the addition of dilute sulphuric acid, however, only a minute quantity of carbonic acid was evolved. After evaporating the solution to dryness, and separating the excess of sulphuric acid by heat, the residue was dissolved in water, the residual silica washed, and magnesia precipitated from the filtrate, as ammonio-phosphate of magnesia. The composition of the precipitate was:

Silica	....	....	....	55.52
Magnesia	....	....	....	3.15
Water (<i>estimated by loss</i>)			....	41.33
				<hr/>
				100.00

It may, therefore, be regarded as a mixture of 9.69 per cent. steatite, with 90.31 per cent. silica precipitated by alcohol. The decomposition of the bicarbonate of magnesia by silicate of potash is, however, fully proved by this experiment. Therefore there cannot be any doubt that the alkaline silicates contained in felspar would, by the long continued action of water containing bicarbonate of magnesia, be decomposed; that silicate of magnesia would be formed, and alkaline carbonates carried away by the water.

47. Bicarbonate of iron is decomposed by alkaline silicates; proto-silicate of iron, and alkaline carbonate being formed.

On adding a dilute solution of silicate of potash to a concentrated solution of bicarbonate of iron, the liquid became green, showing that decomposition had taken place. However, the colour soon passed into yellowish green, and after a few days, the green tint disappeared altogether; so that the same alteration of colour took place that is observed in rocks coloured by proto-silicate of iron, when this substance is oxidized. When ammonia is added to the solution of bicarbonate of iron, a faint greenish coloration is produced; but it soon passes into ochre brown, while

hydrated peroxide of iron is deposited. Ferrocyanide of potassium produces an almost white precipitate, which soon becomes blue. Comparing these reactions with those presented by solutions of silicate of potash, and of bicarbonate of iron, there are no grounds for the supposition that the green colour produced, was owing to the presence of free potash in the silicate of potash; for on adding the solution of silicate to that of bicarbonate of iron, the lower portions of the liquid retained the green colour much longer than when free alkali was added to it under the same conditions, and even at the end of twelve days, the former liquid was almost clear, only a small quantity of ochre brown flocks having been separated. It is therefore very probable that silicate of potash converts bicarbonate of iron, into proto-silicate. The fact that the green earth of the sedimentary strata, is not very liable to oxidation, by the air and preserves its colour,* is moreover consistent with the above results. As the solution of bicarbonate of iron, mixed with silicate of potash, remained clear so long, while on the addition of ammonia or ferrocyanide of potassium, precipitates were so soon formed, it is evident that protosilicate of iron is more soluble in water, than hydrated peroxide of iron, or prussian blue. This circumstance affords a clue to the deposition of green earth from water in drusy cavities.†

48. Hydrated peroxide of iron decomposes silicate of soda. Hydrated oxide of iron, was digested for three days with solution of silicate of soda at the ordinary temperature. The filtered liquid was at first clear, but soon became turbid and brownish yellow. During the washing of the residue, the same change took place, but when the washing was continued without interruption, the filtrate continued clear. If on the contrary, the residue became dry upon the filter, and was again washed, the filtrate became brown. This took place several times successively, but when the filtrate left no residue on evaporation, the washing was discontinued. The residue had the composition I.

When a portion of the filtrate from this residue was evaporated to dryness, there remained a brownish yellow mass, which, when moistened with water, floated upon the surface, and on filtering the liquid, the clear filtrate afterwards became brown colored.

As there was no possibility of separating the iron in this way from the liquid containing silicate of soda, the whole was mixed with hydrochloric acid, which produced a copious effervescence,

* Chap. xxvi.

† Ibid.

owing to the absorption of carbonic acid by the soda during evaporation. Although the residual silica was repeatedly digested with strong hydrochloric acid, it could not be decolorized entirely. After long continued washing, drying, and ignition, it was slightly grey, and therefore still retained a little iron: it amounted to 49.62 per cent.

The yellowish filtrate from this silica was concentrated by evaporation, and gave with ammonia a light brown precipitate having the composition II.

The filtrate from this precipitate was again evaporated to dryness, and after digesting the residue with water, there remained a dark brown residue having the composition III.

The liquid filtered from this residue had the composition IV, calculating the chloride of sodium as soda.

The following results express the per centage proportion of the several substances in reference to the mixture of oxide of iron and silicate of soda.

	I.	II.	III.	IV.	Sum.
Silica	0.98	0.33	0.67	49.62	51.50
Soda ....	...	...	...	44.32	44.32
Peroxide of iron	3.84	0.26	0.08	...	4.18
	4.82	0.59	0.65	93.94	100.00

The reaction, therefore, took place between 4.18 parts oxide of iron and 95.82 parts silicate of soda, and it follows, from these experiments, that hydrated oxide of iron decomposes silicate of soda at the ordinary temperature, and that silicate of iron is formed. Further experiment must decide whether the decomposition may be complete, and if so, what proportion of hydrated oxide of iron would then be requisite.

The oxygen quotient of the silicate I is 2.261; that of II, 0.455; and that of III, 0.08; so that the basic silicate I was decomposed into a less basic silicate, II, and an acid silicate, III, the former being dissolved by the acid liquid, and the latter in the water used for the washing, while another portion remained undissolved. I have not been able to ascertain the cause of the brown coloration, and of the accompanying deposition of the silicate from solution. There was no possibility of the presence of protosilicate

of iron, which would indeed be inconsistent with the circumstance already mentioned, that after discontinuing the washing, the brown coloration of the clear filtrate again took place; for the moist residue upon the filter was sufficiently exposed to the air to become oxidized if protosilicate had been present. Moreover, the filtrate from I, after being evaporated to dryness and digested with water, again presented this brown coloration.*

It is not improbable that the silicate of iron (III) was not precipitated by ammonia, on account of the presence of the large quantity of silicate of soda in the solution.

The circumstance that the silicate of iron, produced by the decomposition of silicate of soda by hydrated peroxide of iron, passes through so many phases of separation, is particularly interesting. It can only be accounted for by the great chemical affinity of silica and oxide of iron. The three silicates obtained by the above reaction are not easily decomposed by hydrochloric acid; the silicate III was not completely decomposed when digested for forty-eight hours with this acid; complete decomposition could only be effected by hydrofluoric acid.

These peculiarities are likewise observed in the analysis of ferruginous minerals; the silica separated in the usual manner is generally yellowish, and it is only by repeated digestion with hydrochloric acid that it can be rendered white; even then traces of iron are found after removing the silica by means of hydrofluoric acid. It would be absurd to suppose that this iron was merely mixed with the silica; it must be combined as silicate, which resists the decomposing action of hydrochloric acid. When the oxide of iron separated in the analysis of ferruginous minerals is examined it is found to contain estimable traces of silica. The lime and magnesia precipitates and the filtrate from the ammonio-phosphate of magnesia likewise contain minute quantities of ferruginous silica.

These facts show that the processes employed in the analysis of ferruginous minerals are inadequate to effect a complete decomposition of the silicate of iron, and that the chemical affinity of silica for the oxide of iron is very great, and this affinity accounts for the important part which the silicates of iron play in metamorphic processes. It would scarcely ever happen that

* From a geological point of view, it did not appear important to follow out the conditions of this remarkable appearance; but if it should turn out that silicate of iron exists in different modifications which differ in their solubility, the fact would certainly have bearing upon the deposition of this silicate from water, and in any case these experiments ought to be continued.

water, filtering through rocks, did not contain in solution carbonate of iron, which so readily passes into hydrated peroxide; consequently the conditions for processes in which this substance exercises a decomposing influence, may be regarded as constant. The experiments described above show, however, that under certain conditions, not well understood, silicate of iron and, without doubt, protosilicate of iron likewise, may be dissolved by water to no inconsiderable amount, and removed.

This latter circumstance accounts for the frequent occurrence of green-earth and glaukonite, and the remarkably difficult decomposition of the artificial silicate of iron is in accordance with the difficult decomposition of green-earth, which is not acted upon by acids, either before or after ignition, and with the great degree of stability which characterizes this mineral.

49. Hydrated oxide of iron decomposes silicate of alumina. The sparing solubility of silicate of iron, and the easy solubility of silicate of alumina, and of freshly precipitated hydrated oxide of iron in hydrochloric acid, admit of this reaction being observed with ease. Equal volumes of thoroughly washed silicate of alumina and hydrated peroxide of iron, in a pasty state, were mixed with equal quantities of water; the former required 120 grains, the latter 360 grains, of hydrochloric acid for perfect solution. The same quantities of silicate of alumina and hydrated peroxide of iron were then mixed together with water, digested for forty-eight hours at a moderate heat, and then mixed with 480 grains of hydrochloric acid. Only partial solution was effected, and there remained a reddish-brown mass.* As the acid added was sufficient for the perfect solution of both substances in the unaltered state, it might be inferred that the residue indicated decomposition had commenced. When the liquid was filtered, the first portion of the filtrate was quite colorless, but it soon became yellowish, and afterwards the whole filtrate acquired this color. When, however, the residue on the filter was carefully washed, and the liquid collected apart, it presented a dark reddish yellow color, the residue having at the same time diminished considerably. The first filtrate (I) and the washings (II) were evaporated to dryness, and the residues, together with that remaining upon the filter III analysed. The results were:—

* In a previous experiment the digestion was continued only for twenty-four hours; the same result was produced, but the residue was so small that it could not be separated from the filter.

	I.	II.	III.	Sums.
Silica	14.88	0.87	0.20	15.93
Alumina	13.13	4.76	0.20	18.09
Oxide of iron	44.88	17.46	3.64	63.98
	72.87	23.09	4.04	100.00

The very different composition of I and II shows that the substance dissolved by the acid liquid was very different from that dissolved by the water. While the quantity of silica in I is rather greater than that of alumina, it is in II barely $\frac{1}{6}$ of the alumina.

The oxygen quotient* of the silicate of alumina employed in this experiment, was nearly = I. There can be no doubt that II and III are double silicates; for the bases in II, which was extracted by water, could only have been rendered soluble by combination with silica, and in III, the oxide of iron must likewise have been combined with silica, because it would not otherwise have escaped solution by hydrochloric acid. In I, there was, no doubt, oxide of iron dissolved by the hydrochloric acid, and though it cannot be decided, whether any portion of this oxide was combined with silica, there can be no doubt such was the case.

It is remarkable that such a minute quantity of silica as that in II, should form with alumina, and oxide of iron, a silicate, soluble in water; if it were regarded as a double silicate, it would present the remarkably high oxygen quotient = 15.6. The oxygen quotient of the insoluble silicate of alumina, and oxide of iron = 11.4.

These experiments show, that hydrated peroxide of iron decomposes silicate of alumina in such a manner, that there is a partition of the silica between the bases, and a double silicate formed. With regard to the remarkable circumstance, that the acid solution I, although containing 2.6 times as much oxide of iron as the water solution II, was pale yellow, while the latter was dark reddish yellow, it can only be conjectured that after the action of the hydrochloric acid, there remained a basic silicate of iron and alumina, which was insoluble in the acid liquid, but soluble in water, and that the dark colour of the liquid II, was owing to the solution of this silicate.

* Chap. xxv.

When, therefore, minerals containing silicate of alumina come in contact with water, containing bicarbonate of iron, the conversion of this substance into hydrated peroxide, provides the condition for the introduction of iron into these minerals, without increase in the quantity of silica. As double silicates of alumina and iron, such as II, are tolerably soluble in water, it may happen that a part of the alumina is at the same time separated by water, in which case the silica would be somewhat diminished.

In order to ascertain the relation of a solution of bicarbonate of iron, to silicate of alumina, a mixture of seventy ounces of a saturated solution of bicarbonate of iron, and of pasty silicate of alumina, was made in a well closed flask: no gas was disengaged, and there did not appear to be any alteration produced. At the end of two days, a minute quantity of peroxide of iron had been formed by the atmospheric air remaining in the flask, and was deposited upon the alumina; and although the flask was kept closed throughout the experiment, hydrated peroxide was continually deposited: partly upon the sides of the flask.

At the end of twenty-six days, the liquid was filtered, and the filtrate evaporated to dryness. Hydrated oxide of iron, containing some silica, was deposited meanwhile. The oxide of iron, adhering to the sides of the flask, could only be removed from the flask by hydrochloric acid, and likewise contained some silica. The deposit collected upon the filter was washed with dilute hydrochloric acid, as long as iron or alumina could be detected in the filtrate. By this means, I sought to separate the silicate of alumina, and oxide of iron, from any silicate of iron that might have been formed, and which would have remained on the filter. A brownish residue was left, which had all the appearance of silicate of iron, and which dissolved only after repeated action of boiling hydrochloric acid. After evaporating the solution to dryness, 0.20 grain of silica was separated.

These experiments were attended with great difficulty, on account of the minute quantity of the three deposits. This silica, obtained by evaporating the solution to dryness, might have originated from silicate of alumina that was in solution, for artificially prepared silicate of alumina is somewhat soluble in water.* However, the silica obtained from the deposit could only originate from silicate of iron, formed by the reaction of bicarbonate of iron with the silicate of alumina.

Taking these three experiments together with the previous

* Chap. xxvi.

ones, there can be no doubt that bicarbonate of iron, abstracts from silicate of alumina a portion of its silica, either to form protosilicate of iron, which is afterwards oxidized, or in consequence of the formation of hydrated oxide of iron.

Although experiment did not furnish any result that would indicate that alumina had been displaced by hydrated oxide of iron, still there are numerous phenomena of mineral alteration; such for instance as the decomposition of wernerite,* that render the reaction extremely probable.

It cannot be supposed that water ever contains hydrated peroxide of iron, but carbonate of iron is almost constantly present. When therefore water comes in contact with a mineral containing silicate of alumina, all the conditions for decomposition, whether partial or entire, are present; the protoxide of iron passes by oxidation into peroxide, and this reacts with the silicate of alumina, while the carbonic acid liberated at the same time, decomposes other silicates in the mineral.

50. Hydrated peroxide of iron decomposes silicate of lime. The experiment was made in the same manner as the last, and with the same quantities of hydrated oxide, and silicate of lime; and as silicate of lime requires less hydrochloric acid for solution than silicate of alumina, a proportionate quantity was added to the liquid, in which these substances had been digested for forty-eight hours. The acid filtrate was pale yellow, as in the last experiment; the washings II, reddish yellow, and the residue III, reddish brown. Analysis gave:—

	I.	II.	III.	Sum.
Silica	11.42	0.52	1.33	13.27
Lime	9.86	traces	..	9.86
Oxide of iron	58.48	11.76	6.63	76.87
	79.76	12.28	7.96	100.00

Although these proportions are similar to those in the last experiment, there is this difference; that by the action of hydrated oxide of iron upon silicate of alumina, there is formed a silicate of alumina, with a smaller proportion of silica, and silicate of iron; the former being dissolved, together with the excess of oxide of iron, by hydrochloric acid, while the latter remains undissolved.

* Chap. xxix, Nos. ix to xiii.

The washing water then decomposes the silicate of iron into a more basic silicate, which dissolves, and a less basic silicate that remains on the filter.

The formation of silicate of iron in this instance is proved by the fact, that the residue III required to be digested for twenty-four hours with hydrochloric acid, in order to separate the oxide of iron, and still the residual silica was slightly yellow colored.

This experiment shows distinctly, that silicate of lime, whose oxygen quotient = 0.407, is decomposed by hydrated peroxide of iron, into silicate of lime, whose oxygen quotient = 0.473, and silicate of iron, whose oxygen quotient = 5.733. This silicate of iron is decomposed by water, into a soluble silicate, whose oxygen quotient = 13.044, and an insoluble silicate, whose oxygen quotient = 2.876. The former, more basic silicate, amounts to about 1½ times as much as the latter, less basic silicate.

51. Hydrated peroxide of iron exercises but little decomposing action upon silicate of magnesia. The solubility of these substances in hydrochloric acid, was estimated as in No. 49, and equal quantities of them were mixed with water, digested for two days at a moderate heat, and then mixed with the quantity of hydrochloric sufficient for their solution. A small portion remained undissolved, but it diminished during the filtration so much, that the reddish brown residue upon the filter could not be separated. Consequently, hydrated oxide of iron is incapable of forming silicate of iron to any extent by reaction with silicate of magnesia.

52. Aluminate of magnesia is decomposed by silicate of soda. The aluminate of magnesia was prepared by Abich,* by mixing a solution of a magnesian salt, containing enough chloride of ammonium to prevent precipitation by ammonia, with a solution of alum, in which the oxygen of the alumina amounted to three times as much as that of the magnesia. When the alumina was precipitated by ammonia, the filtrate was found not to contain more than a trace of magnesia, and he inferred therefore, that it was precipitated in combination with alumina.

Aluminate of magnesia cannot however be prepared in this way, for if magnesia were precipitated, together with alumina, by ammonia, from solution containing chloride of ammonium, this would take place in the ordinary course of analysis, which is not the case. I repeated Abich's experiment, taking however only one-half as much sulphate of magnesia, and still the filtrate gave a

* Poggendorff's Annalen. xxiii, 355.

sensible reaction with phosphate of ammonia. The precipitate was washed until the filtrate gave no reaction with phosphate of ammonia, or chloride of barium. It had the composition I, and dissolved in 29217 parts of water.

When a portion of this precipitate was digested for twelve hours with solution of silicate of soda at a moderate temperature, the residue collected by filtration, and thoroughly washed, had the composition II, while the filtrate had the composition III.

	I.	II.	III.	Sum.
Silica ....	...	10·15	40·08	50·23
Soda ....	...	...	43·23	43·23
Alumina	60·46	5·61	0·50	6·11
Magnesia	2·34	0·43	...	0·43
Water....	37·20	...	...
	100·00	16·19	83·81	100·00

Therefore a portion of the silica of the silicate of soda had combined with the greater part of the alumina, and with the whole of the magnesia forming a double silicate of alumina and magnesia, while a small portion of the alumina was dissolved by the partially decomposed silicate of soda.

This experiment shows that silicate of soda decomposes a compound of alumina and magnesia, and that silicates of alumina and of magnesia are formed. The solution of a portion of the alumina by the silicate of soda solution agrees with the reaction No. 39; for the proportion of this earth to the magnesia was such as to justify the opinion that the precipitate was a mixture of aluminate of magnesia with alumina.

Another mode of preparing aluminate of magnesia was adopted. A boiling solution of potash was saturated with alumina and mixed with solution of sulphate of magnesia until no further precipitate was formed. The filtered liquid contained excess of sulphate of magnesia, although it had an alkaline reaction. The precipitate was washed until the filtrate no longer gave any reaction with phosphate of ammonia, or with chloride of barium.

The aluminate of magnesia, dried at 212 F., had the composition I, and in the anhydrous state the composition II. If the oxygen of alumina in spinelle is threefold that of the magnesia, III will represent the composition of this mineral, the magnesia

amounting to 5·81 per cent. more than in the artificial aluminate ; so that, although the latter method of preparing aluminate of magnesia gave a substance containing far more magnesia than that obtained by the former method, still the percentage was less than in spinelle. But as the precipitate was washed until the filtrate no longer gave reaction with phosphate of ammonia, it must have been a chemical compound of alumina and magnesia that remained.

This aluminate of magnesia, in a gelatinous state, was digested with solution of silicate of soda* for twelve hours, at a moderate temperature, the insoluble portion separated by filtration and washed, had the composition IV ; the filtrate the composition V.

	I.	II.	III.	IV.	V.	Sum.
Silica ....	..	..	..	11·25	34·62	45·87
Soda ....	..	..	..	..	37·03	37·03
Alumina	50·47	77·13	71·32	12·76	0·43	13·19
Magnesia	14·96	22·87	28·68	3·91	..	3·91
Water	34·57	..	..	..	..	..
	100·00	100·00	100·00	27·92	72·08	100·00

In this experiment the quantity of silica of the silicate of soda that was transferred to the alumina and magnesia is proportionately larger than in the previous experiment, and this must be ascribed to the presence of a larger quantity of magnesia. The decomposition of aluminate of magnesia by silicate of soda is therefore more distinct in this instance. In both experiments, however, the greater part of the alumina remains as silicate in the insoluble residue, and only a small portion is dissolved as aluminate of soda. But since, according to the experiment, No. 39 solutions of alkaline silicates extract minute quantities of alumina from silicate of alumina, the whole of the alumina might be extracted from this insoluble residue by the prolonged action of alkaline silicates. It was not ascertained whether the alumina dissolved in the solution of alkaline silicate was in the state of silicate, and as the quantity was very small, this would have been

* The silicate was the same as that employed in the previous experiments ; its composition was not ascertained directly, but it may be inferred from the sum results of the two experiments, which correspond within 1·6 per cent., a difference that is not to be wondered at in experiments with this silicate, which is so liable to alteration by the carbonic acid of the atmosphere.

very difficult. But if, as is probable, it was dissolved as silicate, the whole of the alumina might be extracted from aluminate of magnesia by the prolonged action of alkaline silicates, until at last only silicate of magnesia would remain.

In Chapter XLI it will be shown that the decomposition of aluminate of magnesia by the prolonged action of alkaline silicates, is calculated to afford an explanation of the occurrence of pseudomorphous steatite after spinelle.

53. Arsenous acid decomposes bicarbonate of lime. Fragments of arsenous acid, immersed in a solution of bicarbonate of lime, were for the most part dissolved after some weeks. When the solution was evaporated to dryness, and the residue digested with water, oxalate of ammonia produced a somewhat considerable reaction in the liquid.

54. It may be conjectured with much probability, that *confervæ* growing in water containing chloride of magnesium, and bicarbonate of lime may effect an interchange of the constituents of these salts, so that carbonate of magnesia and chloride of calcium are formed.* If such a change takes place in sea-water, the chloride of calcium would be decomposed by the sulphate of magnesia in sea-water producing sulphate of lime, and reproducing chloride of magnesium, so that by this action the quantity of chloride of magnesium in sea-water would not be altered, but only that of sulphate of magnesia, a salt which is carried into the sea by rivers in considerable quantity.†

55. Chloride of sodium appears to be decomposed by carbonate of lime; at least it is a well known fact that chloride of sodium in contact with moist limestone gives rise to an effervescence of carbonate of soda.

56. Borate of lime, dissolved in water, is decomposed by silicate of soda with formation of borate of soda and silicate of lime. This reaction is most evident when the borate of lime is prepared by precipitating a solution of chloride of calcium with borate of soda.‡

57. Artificially prepared tungstic acid decomposes both neutral and acid carbonate of lime and sulphate of lime. A mixture of the hydrated acid with bicarbonate of lime solution presented, after some hours, numerous microscopic acicular crystals upon the sides of the vessel, and bubbles of gas escaped from the liquid. A mixture of chalk, tungstic acid, and water placed in a flask,

* English edition, i, 191.

† Ibid. 82.

‡ German edition. ii, 946.

with a tube dipping into lime water, gave off by the heat of the hand carbonic acid. After some days, crystals were deposited upon the sides of the flask, and continued to increase during several months.

A solution of sulphate of lime mixed with tungstic acid deposited crystals after three days. A concentrated solution of chloride of calcium was not rendered turbid by tungstic acid, and it was only after a long time that the sides of the vessel became covered with a very thin incrustation of tungstate of lime.* As these decompositions take place slowly, the tungstate of lime has an opportunity of crystallizing.

CHAPTER XXV.

SILICATES.—GENERAL REMARKS.

THE crystalline rocks, and many sedimentary strata which constitute by far the greater part of the known surface of the earth, consist chiefly of silicates, and therefore a knowledge of the chemical character of these substances is of great importance for geology. Hitherto this has been too much neglected, and the chemical phenomena of geology have merely been noticed incidentally in works treating of mineralogy or geology, but the descriptive sciences do not pretend to go beyond correct representation of observed facts; it is the function of chemistry to account for these facts, or to investigate their genetic history.

From a chemical point of view, silicates may be divided into two classes, viz., those which are decomposed, and those which are not decomposed by acids; but the difference is by no means absolute, for by the prolonged action of hydrochloric acid upon felspar, with the aid of heat, small quantities of bases, and even of silica are extracted, and there is no reason for supposing that the felspar might not be entirely decomposed by continuing this action with fresh quantities of acid for a very long time.† Under

* According to Anthon, alkaline tungstates precipitate chloride of calcium perfectly, even in presence of a small excess of acid.

† Forchhammer—Poggendorff's Annalen, xxxv, 353—found that felspar might be decomposed by water at a high temperature. The action of water at 302 F., in a Papin's digester, was so distinct that the water became alkaline to

ordinary circumstances, this action could only be exercised by carbonic acid, but then the duration of the action may be so extended, that the whole of the alkaline silicate may be decomposed; its base washed away by water, and only silicate of alumina left.

Some silicates which are not decomposed by acids, when unaltered, are readily decomposed when previously somewhat altered. Thus, for instance, Dobereiner* found that weathered silicious magnesite, dissolved completely in dilute sulphuric acid, and that the silica did not separate until the liquid was evaporated, while the unaltered mineral acted upon in the same manner, gave a residue of silica.† The presence of silicates in the water of springs has already been treated of.‡ According to Damour§, the water of the following springs contains only silicates:

			Geyser.	Laugar.	Radstofa.	Hvergardin.	Store-Huer.
Silica	....	....	0.52	0.14	0.26	0.32	0.32
Soda	....	....	0.34	0.09	0.25	0.32	0.31
Potash	....	....	0.01	..	0.01	..	0.02

There can be no doubt that silicates likewise exist in river and sea-water, although in such small quantity as not to be recognizable with certainty.

Some silicates, especially garnet, vesuvian, and epidote, are decomposed by acids only when previously ignited or melted. This fact is supposed by Von Kobell to be owing to a diminution of the attraction of the constituents, simultaneous with the destruction of the crystalline state by fusion. But according to his own observations, many specimens of garnet did not melt at a red heat, and indeed did not show any signs of alteration, although after ignition, they formed a jelly with hydrochloric acid, so that there seems to be some inconsistency between his experiments and inference. With regard to those kinds of garnet which are decomposed by acids, after fusion, it is possible to suppose that

litmus paper. The action increased with the temperature, and at 432° F. was so great that by evaporating the water mixed with hydrochloric acid, and adding chloride of platinum, the double chloride of potassium and platinum could be obtained.

* Schweigger's Journal, xiii, 323.

† L'Institut, 1847, xv, 46.

‡ English edition, i, 4, et seq.

§ Karsten's Archiv., v, 165, and x, 15.

they were formed by plutonic action, because the crystalline state is destroyed by fusion and rapid cooling. But it is impossible to suppose that a mineral formed by plutonic action, and not decomposable by acids, would become decomposable by heating it to a degree insufficient to destroy its crystalline state, for it would already have been exposed to the same temperature, while cooling down from the temperature at which it had acquired the crystalline state. Indeed, no other difference can be imagined, than that the reduction of temperature after the crystallization of the mineral was extremely slow, while in the experimental instance it was rapid. But it cannot be supposed that such a difference in the time of cooling, would induce such a chemical difference in a mineral substance, that in the one case it would be decomposed by acids, while in the other it would not.

Berzelius* accounts for the decomposition of ignited garnet and vesuvian by acids, by the supposition that the silica is in the insoluble state, and that when they are ignited, it passes under the influence of the strong bases, into the soluble state. Simultaneously with this alteration, the density of the minerals alters. The decomposition of zeolites, containing lime and alumina, by ignition, admits of the inference, that their solubility in acids, is not owing to the presence of water, for on account of the preponderating quantity of silica, they are converted into the insoluble state, and are no longer decomposed by acids.

Several varieties of clay present the same character; in their native state they are either not decomposed at all by acids, or only with difficulty; but are easily decomposed after ignition. Diaspore, a hydrate of alumina, is insoluble in sulphuric acid, but is rendered soluble when the water has been separated by ignition.† These are striking instances of the fact, that minerals which have undoubtedly been formed in the wet way, become decomposable by acids after ignition, and loss of the hydrate water. This view also accounts for the fact, that in the case of garnet, fusion is not always necessary, in order to render it decomposable by acids; for the ignition of alkaline minerals with baryta shows that the conversion of silica from the insoluble to the soluble state, may be effected without fusion. On the other hand, it cannot be wondered at, that silicates soluble in water, should pass into the insoluble state in crystallizing, for silica itself undergoes this change, as is

* *Lehrbuch der Chemie*, 5^{te} ed. iii, 484.

† Damour—*Journ. für prakt. Chemie* xxxvii, 491.

sufficiently shown by the silicious minerals formed in lodes, drusy cavities, &c.

Since the silica in garnet, &c., passes into the soluble state by ignition, it might be inferred, if the mineral had been formed by plutonic action, that the silica was originally in the soluble state, and had been rendered insoluble by slow cooling, while by rapid cooling it had retained the soluble state; but this is altogether inconsistent with the facts observed in the formation of glass: here the cooling is rapid, but the silica is in the insoluble state, and the more perfect the vitrification, the less is the substance acted upon by acids.

The chemical reactions treated of already* have been applied with greater or less success in tracing the genetic history of compound silicates; and there would have been more certain ground for this proceeding if the simple silicates had been as numerous as the compound silicates. It would then be possible to proceed from a knowledge of the simple silicates, and to arrive at results as certain as those relating to artificial double salts. But this cannot be done; for the analysis of the compound mineral silicates would indicate the existence of no less than thirteen compounds of silica with bases:—a neutral silicate, five acid, and seven basic, silicates. Moreover, we have seen† that silicates dissolved in water, are decomposed during evaporation, at the ordinary temperature, into acid silicates and basic silicates, which do not seem to present any definite proportionality of constituents.

The application of the law of isomorphism, according to which substances of analogous composition may mutually replace each other, has thrown much light upon the nature of the composition of minerals; but it was carried too far, and assumptions were made without the authority of direct experience. Rammelsberg‡ remarks, with great justice, that isomorphism cannot necessarily or in all cases depend upon an analogous grouping of elements.§ On this account recourse has been had to the doctrines of atomic volume, heteromerism, &c., and the subject has only been rendered more complicated.

Notwithstanding the numerous accurate analyses of felspar, mica, augite, and hornblende, no general formula can be laid down as expressing the composition of any of these minerals. Notwithstanding the great resemblance between the individual

* Chap. i and xxiv.

† Poggendorff's *Annalen*, lxx, 449.

‡ English edition, ii, 58, No. 34.

§ Ibid. ii, Chap. xxx.

members of these species in physical characters, and the ease with which their relations in this respect may be traced, still the discrepancies in their composition are equally great. One type of crystal form, varying scarcely more than in the case of isomorphous substances, comprises all the substances usually called feldspar; however, the chemist must separate these substances when he finds that the individual members, orthoclase and albite, oligoclase, labrador and anorthite, cannot be regarded as the result of substitution of isomorphous substances, but that they present essential differences in their composition; for while the oxygen ratio of the alkalies and lime to alumina is in all of them = 1 : 3, the oxygen ratio of silica varies = 4 : 6 : 9 : 12.

In pseudomorphs the chemical composition is entirely altered, especially in the displacement pseudomorphs, while the crystal form remains unaltered. This is in direct opposition to isomorphism; for although pseudomorphs may be more or less mutilated, still they show that the capability of assuming a definite form peculiar to the chemical composition may under certain conditions be entirely lost.

The classification of isomorphous bases accordingly as they are mutually replaceable seems to have been an important step towards the formation of correct views of the chemical constitution of compound silicates. The one class comprises bases with one atom of oxygen — alkalies, lime, magnesia, protoxides of iron, and manganese: the other class comprises bases with three atoms of oxygen — alumina, peroxides of iron, and manganese. In order to avoid the atomic theory, the bases of the former class may be called *monoxides*, those of the latter class *sesqui-oxides*.

This separation involves the necessity of an accurate determination of the state of oxidation of iron in the analysis of minerals, and when both oxides are associated, the quantitative estimation of each. This applies also to the oxides of manganese. In the older analyses this point has been almost entirely neglected; and, although more recently, methods of separating the oxides of iron have been devised, still the degree of accuracy required for exact analyses has not yet been attained. Therefore the division of these oxides as belonging to one or other class of isomorphous bases is more or less imperfect.

This is not the only difficulty that has to be overcome in order to establish a basis for the representation of the chemical constitution of the compound silicates. Although it has been possible, in the case of those silicates that contain but little iron

or manganese, to arrange the principal bases, still the proportion of silica is rarely such that it can be divided between the bases of both classes, so that the silicates in any one instance would be all of one order. It is then necessary to assume the existence of silicates of different orders, as regards both the monoxides and sesquioxides. In this way opportunity is afforded for the exercise of caprice in the expression of the composition of minerals, as is sufficiently testified by the multitude of discordant formulæ proposed by different chemists for the same mineral, and thus the views of the chemical constitution of the compound silicates have been involved and complicated.

Chemical formulæ can have no value unless they are based upon something more than grounds of probability or analogies of related minerals. In addition to this the chemical composition of minerals is liable to alteration in the course of time, so that if they were originally compounds in definite proportions to express which formulæ might be constructed; these formulæ can no longer be of any avail when chemical alteration has taken place, and the definite proportionality of the constituents has been disturbed.

The ferruginous and manganiferous compound silicates frequently experience alteration by the conversion of the protoxides of these metals into peroxides. A formula, in which the iron and manganese are reckoned among the monoxides, is not applicable to silicates in which these metals, originally in the state of protoxides, have passed into the state of peroxides, either wholly or partially. The reverse case sometimes occurs, though more rarely, when by the reducing influence of organic substances the peroxide of iron is converted into protoxide.

In the conversion of sulphate of iron into persulphate by oxidation, basic persulphate of iron is separated; and by means of this separation the oxygen ratio of the sulphate of iron is not altered by its conversion into persulphate. By analogy we are justified in supposing that in the conversion of protosilicate of iron, in minerals, into persilicate, there is also a separation of basic persilicate. Such a relation appears really to obtain in the oxidation of protosilicate of iron in minerals; for minerals, which in their normal state contain protosilicate of iron, and are not acted upon by acids, are decomposed by acids when they have experienced alteration by oxidation, and it is the basic persilicate of iron which is then dissolved with separation of silica.

The chemical formulæ have two defects: first, that the divi-

sion of the bases into monoxides and sesquioxides is so difficult, and in the case of the older analyses impossible, especially with highly ferruginous minerals; secondly, that it is not known to what order of compound the silicates in the compound silicious minerals belong. In addition to this, alumina appears in many minerals, especially in the aluminous kinds of augite and hornblende, to have the functions of an acid, so that the silicates are associated with aluminates, and in such instances the most diverse states of combination may be supposed to exist among the silicates and aluminates.

In fact, the chemical formula assigned to minerals are nothing else than the expression of the individual views of the chemist who has devised them; they have, therefore, no scientific value, and do not furnish the least representation of the arrangement of the constituents of minerals.

The ratio of the oxygen of the silica, and that of the whole of the bases is, on the contrary, independent both of the partition of the bases as monoxides, or sesquioxides, and of the orders to which the several silicates, in compound silicates, belong; for this ratio may be ascertained directly from the analytical results. Consequently, the most general and comprehensive expression for the composition of a mineral may be obtained by the division of the oxygen of the silica into that of all the bases together, and, for the sake of brevity, I will call this quotient the oxygen quotient.

The determination of this oxygen quotient is undoubtedly liable to errors arising from defective estimation of the different oxides of iron and manganese: but such defects have always a greater influence upon chemical formulæ, in which an erroneous partition of the bases results from inaccurate estimation of these oxides.

By determining the oxygen quotient from the analysis of a mineral that may be regarded as in its normal condition, it would be easy to ascertain whether another specimen of this mineral, whose oxygen quotient is known, is altered or not. But unfortunately it is not known with certainty of any mineral* whether it is altered, or still in its normal condition. It has however been shown how the oxygen quotient may be approximatively determined.†

A diminution of the oxygen quotient may be owing to abstraction of bases, or introduction of silica, or to both circumstances

* English edition, i, 45.

† Ibid, 46.

acting simultaneously; and an increase of the oxygen quotient would result in the opposite case. When bases are separated from minerals, a comparison of the per centage statement of the analyses of the normal and altered minerals, will generally show what bases have been removed.*

The alterations in minerals, for instance, the higher oxidation of iron and manganese compounds, do not take place in atomic proportions; long periods of time may elapse before an entire equivalent of oxygen is assimilated by a mineral substance, and during the interim, no exact formula could be assigned to it. But the oxygen ratio expresses the true composition of minerals, not only in their normal state, but at any and every period of change. When the oxygen ratio no longer corresponds with those simple proportions which are shown by analysis to exist in the normal mineral; this is a positive sign that alteration has commenced.

When a partition of the monoxide bases, from the sesquioxide bases, can be effected with tolerable accuracy, and this may be done more readily in the case of minerals which contain but little iron than in the case of highly ferruginous minerals, the oxygen quotient acquires greater precision by the statement of the oxygen ratios of the two classes of bases. I shall adhere to the usual mode of representing the chemical formulæ with this modification only, that the oxygen ratio will be placed next to the radicals inclosed within brackets, as the numerator, and the oxygen ratio of the silica as the denominator of a fraction. Thus, in vesuvian for instance, the oxygen ratio of the monoxides, sesquioxides, and silica = 3 : 2 : 5; so that it would be expressed by:—

$$\frac{(\text{Ca, Mg, Fe, Mn}) 3 + (\text{Al, Fe}) 2}{\text{Si } 5}, \text{ or by the general formula } \frac{\text{R } 3 + \text{R } 2}{\text{Si } 5} = 1.$$

In garnet, on the contrary, the oxygen ratio between the monoxides, sesquioxides, and the silica = 1 : 1 : 2; and it would be expressed by:—

$$\frac{(\text{Ca, Mg, Fe, Mn}) 1 + (\text{Al, Fe}) 1}{\text{Si } 2} = \frac{\text{R } 1 + \text{R } 1}{\text{Si } 2} = 1.$$

Since the first member of the formula always contains the monoxides, and the second the sesquioxides, the degrees of oxidation of iron and manganese do not require to be specified when they occur in both members or not.

* English edition, i, 49.

Vesuvian and garnet have therefore the same oxygen quotient; and in such instances it is particularly necessary to make a partition of the bases so far as the analysis may permit.

When, as for example in the varieties of augite that do not contain alumina, the degree of oxidation of iron and manganese is undetermined, or at least their relative proportion is unknown, and consequently no distinction can be drawn between monoxides and sesquioxides, but the oxygen ratio between the whole of the bases and the silica = 1 : 2 ; it is expressed by—

$$\frac{(\text{Ca, Mg, Fe, Mn,}) 1}{\text{Si } 2} = 0.5.$$

These formula, however, will be seldom employed, because in cases where the bases, existing in the different varieties of a mineral, are variable, formulæ in which all the bases must be placed together, would afford but little insight into the composition of the mineral. In most instances I shall limit myself to the statement of the oxygen quotient.

Such formulæ as the above, would be purely empirical, and express simply the result of analysis ; while the usual formulæ can be termed rational only when they are not based upon uncertain and capricious assumptions. The former would be liable to alteration only when, by more exact experiments, the oxygen ratios were more accurately determined, and the bases separated with a greater degree of precision. The latter, however, are liable not only to correction from such circumstances, but to perpetual change, according to the ever-varying opinions with regard to the atomic number of elements in their compounds, and the order to which the compounds of bases with silica belong. Thus, for instance, the question whether silica consists of one equivalent of silicium, and two or three equivalents of oxygen, has no influence whatever upon the determination of the oxygen quotient. But if the opinion that silica contains two equivalents of oxygen were to be generally adopted, it would be necessary, in order to prevent confusion of language, to reprint all works containing chemical formulæ for minerals.

While identity in crystalline form may be associated with entire diversity of chemical composition, many minerals, on the other hand, which are almost identical in composition, may present very different physical characters. In the succeeding pages, several instances of this kind will be mentioned. Thus there are altered minerals, which in composition agree with many

varieties of mica, or do not differ from them more than the varieties of mica differ among themselves; and yet these minerals are in no respect more characterized than by the absence of the physical characters of mica.*

If we wish to obtain some leading points of comparison, that may serve as a clue in the investigation of this obscure subject, they must be sought for in the chemical relations of minerals. Isomeric substances show in a striking manner that identity in composition may be accompanied with great diversity of characters. The oxygen, sulphur, chlorine, and other compounds of the metals present numerous illustrations of the remarkable diversity of character that may result from alteration in the quantitative composition of a substance, and there is no doubt that the same relations obtain in the case of minerals. The different isomeric forms of silica, and of the silicates in minerals, sufficiently prove this. The attempts of chemists to classify the silicates, have led to the assumption that there are thirteen orders of compounds of silica with bases, a number which far exceeds that of the compounds of acids with bases that have been prepared artificially, and yet it is probable that the actual number of orders of combination in minerals is far greater. It may therefore justly be supposed that minerals with the same percentage composition may contain silicates belonging to very different orders of combination, and that the character of these minerals will therefore be very different. In the present state of science, it is not possible to recognize the existence of these different orders of compounds by means of analysis.

It must likewise be remembered that minerals do not consist solely of silicates. The occurrence of simple aluminates—spinnelle, gahnite, &c.—and the composition of the aluminous varieties of augite and hornblende, have long since led to the opinion that minerals contain aluminates. If aluminates are ordinarily constituents of minerals; if, moreover, they belong to as many orders of combination as silicates, an indefinite number of possible compounds of these binary compounds may be supposed to exist. This number cannot be found by calculation, because the number of the orders of combination to which silicates and aluminates may belong, cannot be ascertained by analysis. But the greatest diversity may be supposed to obtain in the arrangement of the constituents of minerals which are perfectly identical in percentage composition.

* English edition, ii, chap. xxix.

The locality in which a mineral occurs, its association with other minerals, its alterations and decompositions indicated by pseudomorphs and analyses, as well as its displacement by other substances present individually or together, the safest basis for an opinion as to the mode of its formation. It is for this reason that I shall devote particular attention to this subject in the following chapters. It is only in rare instances that the crystalline form, and other physical properties of minerals will be considered, and when they are intimately connected with their chemical nature.

A complete enumeration of the compound silicates does not lie within the plan of this work. Those silicates only will be treated of, which are of very frequent and general occurrence, and therefore possess considerable geological interest, or whose chemical characters throw special light upon their formation, and that of other minerals.

Minerals occurring in drusy cavities which communicate with the surrounding rock only by narrow openings, can only have been formed by water containing their constituents in solution. When therefore a mineral, whether it be a carbonate or a silicate, hydrated or anhydrous, in microscopic or very large crystals, occurs in such a position, its formation in those instances in the wet way, may be regarded as proved; and by analogy, it may be inferred that it has been formed in the same manner where it occurs in other localities.

It has already been shown* that pseudomorphs can only be formed by processes in the wet way. When therefore a mineral A is found with the crystalline form of another mineral B, the possibility that it has been formed in the wet way, may be regarded as proved. When a pseudomorphous mineral A, has been formed by the alteration of another mineral, B, its direct formation from a water solution is not proved, but when it has been formed by displacement of B, its origin in the wet way is evident.

When well developed crystals, of felspar for instance, are found in sedimentary rocks, and it cannot be shown that the rock has been subjected to the action of any melted mass, the occurrence of a crystallized mineral under such circumstances affords evident proof that it has been formed in the wet way.

The occurrence of minerals in contact with other inorganic or organic substances, that have been previously formed and are decomposed by heat, is an equally evident proof that such

* English edition, i, 36.

minerals have been formed in the wet way. The occurrence of organic remains with determinable forms in rocks, is considered as an unquestionable indication that they have been formed in the wet way, and it is equally certain that chemically recognizable organic remains in a mineral have originated either from the air or from water. These organic remains may have been introduced into the substance of the mineral at the time of its formation or afterwards. In the former case the mineral can have been formed only in the wet way; in the latter case it may have been formed this way, or by fusion. When, together with organic remains, a mineral contains water, and is at the same time more or less decomposed, it is most probable that these substances have been introduced subsequent to its formation, and that the introduction of organic substance and the decomposition have been simultaneously effected by water. Generally speaking, the introduction of organic substances into minerals exposed to the air will most probably have been effected only by means of water.

In the following consideration of minerals my remarks will be especially directed to the production of indisputable evidence of their mode of formation.

In the laboratory, crystallization may be effected both in the wet way and by fusion, although the former is more frequently adopted. It cannot, therefore, be doubted that the formation of crystallized minerals may have taken place, and is still going on, in both ways.

We have an opportunity of observing masses of melted lava issuing from the craters of volcanoes. The great similarity between these masses when solidified, and those which have not been observed in the melted state, indicates a common origin; but, with the exception of lava, scorix, and other volcanic products, there is no rock whose igneous origin can be proved with equal certainty. Lava is, therefore, peculiarly adapted for the study of crystallization by fusion.

When a melted mixture of lead and tin, in any proportions, is allowed to cool slowly, one or other of the metals solidifies first, and remains mechanically mixed with the still liquid portion, which is an alloy of the two metals in definite proportions. By the subsequent solidification of this portion, the mass will consist of a mixture of this alloy with whichever of the metals was in excess.* Such a process may reasonably be supposed to take

* Rudberg—Poggendorff's Annalen, xviii, 274.

place during the slow cooling of lava, the only difference being that a greater number of substances are melted together.

The occurrence of crystalline minerals in the more recent lava is very rare. The products of the latest eruptions in Iceland are indeed rich in crystalline minerals.* Even the much older and perfectly scoriaceous lava of the Auvergne is very rare crystalline; it is only at those points where it has accumulated to a certain height that it contains a tolerable abundance of labrador crystals. The vesicular and scoriaceous lava at Dafiaré, in Abyssinia, is, on the contrary, remarkably crystalline; it contains well-formed crystals 0·''005 in length, which appear to be glassy felspar.† So likewise the lava from the extinct volcanoes in the neighbourhood of the Laacher See and the Eifel is very rarely crystalline. One of these masses of lava at Bausenberg is, however, full of small definitely formed crystals of augite. The crystals of leucite, in the more recent lava at Vesuvius, are much inferior in size and perfection of form to those occurring in the older masses of lava at the same place, and especially in those whose origin is far anterior to the historic period.‡ Wernerite, garnet, and vesuvian occur only in the products of the old Vesuvius, Monte Somma. It cannot be supposed that the conditions for the formation of these minerals by fusion were peculiar to the latter volcano. Medici Spada observed in 1835, ten months after the eruption of Vesuvius, a mass of lava which appeared to have cooled perfectly, but which was quite soft, and had a very high temperature at the interior of its numerous fissures. As he remarked, there was no deficiency either of time or space for the formation of crystals in this lava, and yet these are of such rare occurrence.§ The lava from the eruption of Etna in 1852 presents an actual crystallization; it is for the most part crystalline, and consists of labrador and augite, with isolated granules of olivine imbedded in the mass. The presence of magnetic iron ore is likewise recognizable by a very slight action upon the magnet.||

It is evident that after the solidification and cooling of lava, crystals can no longer be formed by fusion. Therefore, when we

* Bunsen—Poggendorff's Annalen, lxxxiii, 198.

† Rochet d'Hénricourt—Comptes rendus, 1846, No. 20.

‡ Leop. Von Buch—Gilbert's Annal, vi, 59.

§ Eichwald—Nouveaux Mémoires de la Soc. impér. des Naturalistes des Moscau, ix, 259.

|| Kenngott—Sitzungsberichten der Acad. der Wissenschaften zu Wien, ii, 27.

find that the older lava contains crystals which either do not occur at all in the more recent lava, or which are at least much larger and better developed than in the latter; it is certain that these crystals have been formed in some other way than by fusion, and there is no other than the wet way in which they can have been formed. Now since rocks, which unquestionably are of volcanic origin, either do not contain any, or only very small crystalline minerals; since this is the case even in the largest masses of lava that may have been years or even centuries in cooling, the inference that crystals of quartz and felspar, a foot in length, have been formed by fusion, and that rocks, such for instance, as the granite of the Riesengebirge, in the druses of which such crystals occur, were formerly melted masses, is inconsistent both with facts and with the analogy which is assumed to exist between such rocks and lava. Inferences from premises that are not proved, but rest merely on assumed analogies must be erroneous when they are inconsistent with these analogies.

We must, therefore, refrain from regarding crystalline minerals, which occur in volcanic masses, as products of fusion; and from regarding their appearance in these localities as indicative of their formation in this way. There is evidence, as I shall subsequently have occasion to show, of the formation of wernerite in the wet way in localities where the influence of volcanic action is altogether excluded, and there is no reason why this mode of formation should be considered impossible in the older lava which has for long periods been exposed to the action of the water.

Brewster* states that glass, dug from the ruins of the Chapter-house of the Cathedral of St. Andrews, had acquired an heterogeneous and crystalline structure, the metallic particles having separated while the siliceous particles had assumed a regular crystalline arrangement around the centre of decomposition. But if within the historic period glass may acquire crystalline structure, and that evidently by the action of water, it cannot be doubted that the volcanic products analogous to glass may have experienced a similar alteration under the same circumstances, and that after long periods they may have been converted into crystalline masses.

According to Leydolt's† experiments, glass presents a crystalline character when corroded by a mixture of sulphuric and

* British Association Reports for 1840.

† Comptes rendus, xxxiv, 565.

hydrofluoric acids, inasmuch as the crystalline portions are less easily acted upon than the amorphous portion. The crystalline structure of glass described by Brewster may therefore have been pre-existent, and merely rendered sensible by the action of water and carbonic acid. It would seem, therefore, that the effect which sulphuric and hydrofluoric acids are capable of producing in a few moments may likewise be produced by carbonic acid when the action is considerably prolonged. However, as the constituents of the glass were actually separated, there must have been not merely an extraction of the amorphous portion, but a partial decomposition, and therefore the analogy between this instance, and the effect produced by sulphuric and hydrofluoric acids is not perfect. The action of sulphuric and hydrofluoric acids upon volcanic rocks under the same circumstances as in Leydolt's experiments with glass, would probably be an interesting subject of investigation. If as can scarcely be doubted, the effect were similar to that produced upon glass, it is highly probable that the first alteration they would experience, would consist in the extraction of amorphous portions, and that in this way a hidden crystalline structure might be detected.

No one will refuse to admit that the above-mentioned experiments with glass, furnish a considerable support to the opinion that the formation of crystals may take place in amorphous masses after their solidification.

When crystals of a salt are suspended in a solution of the same salt, the dissolved salt is deposited by the gradual evaporation of water, and the crystals are increased in size.* In this way, crystals of several alums have been obtained of unusual size. The result is certainly the same, whether the crystal which is immersed in the solution has been formed by fusion or in the wet way. It might be expected that in analogous manner, the small crystals formed in lava during its slow solidification, would in process of time increase in size. If the entire quantity of the constituents of these crystals was not separated in a crystalline form during the slow cooling of the lava, but remained uncrystallized in the mass, then by the action of meteoric water, continued for long periods, an opportunity was afforded for the gradual solution of the uncrystallized portion. If the prevailing conditions were favourable to the crystallization of this solution,

* Advantage is taken of this circumstance to cause the crystallization of saline solutions, &c.

the small crystals might be increased in size, as is observed in artificial crystallization.

It may, indeed, be supposed that imperfectly formed crystals imbedded in lava, would, subsequently, be rendered perfect by the continuous crystallization in the wet way; for, according to the experiments of Dr. Jordan, the broken edges and angles of crystals are replaced when they are suspended in solutions of the same substance, and it is only after this replacement of deficient portions that the crystals begin to increase in size.

The crystals of gypsum thirteen lines in diameter, which were found on thorns* and had been formed within four or six years, from drops of water containing sulphate of lime, furnish an instance of crystallization that might open the eyes of those who hold plutonic theories.

Compared with the idea of the production of large crystals of quartz and felspar, in lodes, or the druses of granite, from erupted masses in a state of fusion, it must seem irksome and dull to refer their origin to drops of water, and to suppose that their formation extended over an interval far greater than the age of the earth, according to the Mosaic history. But the length of time that must be supposed to have elapsed during the formation of a mineral, or any geological change, can never furnish any ground of objection to a mode of accounting for these phenomena, which is in other respects probable.

Gypsum dissolves in 460 parts of water; the water of some springs contains $\frac{1}{10000}$ silica; so that in twenty-two drops of such water, there is a quantity of silica, equal in weight to the sulphate of lime in a drop of saturated solution of gypsum. We may, therefore, ascertain by simple calculation, that the time requisite for the formation of a crystal of quartz one inch in diameter would, under circumstances otherwise similar, be twenty-two times greater than that requisite for the formation of a gypsum stalactite of the same dimensions. Scarcely more than a century would be requisite for the formation of such a crystal of quartz from water percolating through thorn fagots and depositing nothing but silica, and this crystal would consist of no less than 4,766,652 concentric layers of silica, each about one-millionth of a line in thickness. But as the water of springs rarely contains $\frac{1}{10000}$ of silica, and generally much less, such a period must be regarded as a minimum which in most instances would be doubled, or even further increased; but still we do not find that these

* English edition, i, 426.

periods are in any degree remarkable, compared with geological periods.

These remarks are as applicable to felspar as they are to quartz: for, as this mineral is soluble in water,* we may suppose that crystals of felspar of any size may be formed from water solutions by the juxtaposition of the ultimate molecules. It is in this respect immaterial that, as is probably the case, water does not dissolve felspar without decomposition; for if the water solution contain silica, alumina, and potash in other proportions than that in which they form felspar, still felspar would be separated from such a solution, because the proportion of the constituents of a compound substance in solution does not affect the proportion in which they separate in the crystalline state. In the manufacture of salt, the brine carries away any substances, present in the water, which are not separated in the formation of the incrustation upon the fagots; and in a similar manner the water from which felspar is being formed by crystallization would carry away any excess of silicates which would contribute to the formation or alteration of other minerals.

So long as the dogma, that felspar could be formed only by fusion, maintained its ground, the views which I have endeavoured to put forward were regarded as imaginary; but now that the geognostic, mineralogical and chemical relations of this mineral can be shown to prove its formation in the wet way, it must be admitted that my investigations have been guided by reason and not by imagination. Even among those who adhere to the plutonic theory there are few who would venture to regard zeolites as other than infiltration products; but if this is admitted for analcime, for instance, why should it be disputed in the case of orthoclase, which differs from it only in containing four equivalents of silica more than analcime, with six equivalents of water, and soda in the place of potash?

The formation of large crystals, such as those above mentioned, must, even according to the plutonic theory, have required a great length of time. Even admitting that the materials for their formation were supplied in a pure state, so that a drusy cavity contained melted silica or felspar, it cannot be supposed that the formation of such large crystals could take place rapidly. But when we find crystals of felspar a foot long, and crystals of quartz three or four feet in length, as in the Krötenloch, near Schwartzbach, in the Riesengebirge, it is evident that there must have

* English edition, i, 59.

been a separation of the melted silica from the felspar mass before the formation of large crystals could take place. This separation must also have taken place while the substances were liquid; for after solidification it would have been impossible. It is, however, impossible to form any clear idea of such a separation of melted substances, entirely different in their fusibility and chemical nature, but corresponding very closely in density. It is, moreover, doubtful whether an accurate examination of the relative situation of these quartz and felspar crystals could at all furnish a clue to the way in which such a separation could have been effected, and it is more probable that it would lead to a conviction that such a mode of formation is altogether impossible.

Even putting aside for a moment these difficulties, we must suppose that a juxtaposition of the crystalline molecules took place as in the formation of crystals in the wet way, but much more rapidly; for the crystalline solidification must have proceeded from the exterior, inwards. If indeed the crystals of quartz and felspar in drusy cavities were always blended as in graphic granite, which is indeed frequently the case, the possibility of forming some idea of the process assumed by the plutonic theory, would be somewhat greater. But the attempt to furnish a satisfactory explanation of this process, is more properly the province of those who recognize the plutonic theory.

In the German edition of this work, I have given several illustrations of the crystallization of amorphous masses without previous solution.* Since then, H. Rose† has observed that the voluminous precipitate produced by a solution of carbonate of potash in sulphate of cobalt, is converted within three days into a cluster of definite crystals. The precipitate produced by carbonate of potash in sulphate of nickel, yielded within a few weeks, crystals of somewhat considerable size. Similar phenomena are presented by minerals, thus coralline-limestone is gradually transformed into an aggregate of calc-spar crystals. According to Marcel de Serres, and Figuier,‡ muscle shells when long exposed to the action of sea water, are transformed into a similar crystalline aggregate. On the coast of Algiers, they are sometimes found transformed into brilliant white limestone with crystalline granular structure.

It cannot be determined by experiment, whether in these

* German edition, ii, 332.

† Poggendorff's Annalen, lxxxiv, 554 and 556.

‡ Ann. des Sciences Nat., 1847, January, p. 21.

instances of crystallization, there is a previous solution of the substances. However slightly soluble some substances may be, it is certain there are few which are absolutely insoluble; and it may, therefore, be supposed that in the transformation of substances from the amorphous to the crystalline state, very minute quantities are dissolved, and again deposited. When such substances are saturated with water, and when, as in rocks, this water is constantly renewed, the conditions are favorable to the continual alternation of solution and crystalline deposition.

There is no doubt that the transformation of amorphous masses into a crystalline state, very frequently takes place in minerals; and we may suppose that in a perfectly amorphous lava which is constantly permeated by water, crystalline minerals may be gradually separated, which are in vain sought for in recently solidified lava. The same remark applies to amorphous masses which have been deposited from water. The analyses of clay-slate show that it consists chiefly of a substance having the composition of felspar, so that it contains the material for the formation of felspar crystals, and, therefore, it is not surprising that such crystals should occur in many kinds of clay-slate. These crystals have originated from the amorphous feldspathic mass in the same manner that crystals of calc-spar have originated from amorphous carbonate of lime in coralline limestone. In both instances it is certainly water alone that has effected the crystallization.

Silicates are either hydrated or anhydrous. The presence of water as a normal constituent of a mineral can be ascertained only when the mineral is in so perfect a condition that no alteration of its characteristic appearance can be detected. When different specimens of the same mineral are found to contain different quantities of water, and when the quantity of water is greater in proportion to the altered appearance of the mineral, there is no doubt that the water is not a normal constituent of the mineral, but has been introduced by some process of alteration; for it is by means of water that substances which produce alteration of minerals are introduced.* A more or less advanced alteration of a mineral may be inferred from the evolution of water at 212° F., for this is an indication that the decomposing agent has already been introduced into the substance of the mineral. Those rocks, for instance, give off a large quantity of water, which by their external appearance are known to have suffered considerable alteration. When hydrates have been

* English edition, i, 36, 52, et seq.

formed, as for instance, hydrated peroxide of iron, hydrated silicate of alumina, &c., the mineral, after being dried at 212° F., gives off a further quantity of water when the heat is increased.

M. Scheerer* is of opinion that there is a peculiar kind of isomorphism which he terms polymeric, and which consists in the substitution of water for magnesia. He considers that this polymeric isomorphism plays a considerable part in respect to the composition of minerals. However, Scheerer's views have been controverted by Rammelsberg, Naumann, and Haidinger, and I have myself pointed out objections to them.†

When minerals, that were originally anhydrous, take up water, and are thereby more or less altered, it generally happens that organic substances are introduced. This is indicated during the chemical analysis by the empyreumatic odour, and frequently alkaline reaction of the water separated by heating the mineral. The earths and the silica when separated, are then generally grey, or even black, and do not become white until after they have been ignited for some time in contact with air.

In the analysis of pseudomorphs, these characters are presented in a remarkable degree, and this is a further proof that the pseudomorphic processes have taken place in the wet way.‡

The minute quantities of water which are frequently present in minerals, cannot have introduced the organic substances, the quantity of which is frequently considerable, and even estimable; the introduction of these substances has been effected by the water which has percolated through the rocks during long periods and in considerable quantity.

It is by means of organic substances, moreover, that the persilicates of iron are so frequently converted into protosilicate and carbonate of iron, as in the deposits from water.

When the analyses of a mineral show that water is always present in constant proportion, it must be regarded as an essential constituent. Since however hydrated minerals, as for instance laumontite, are subject to alteration, by which they either lose a portion of their water even at the ordinary temperature, or are converted into other hydrated minerals, the amount of water in such minerals may vary when changes of this nature have commenced. Therefore the normal proportion of water in minerals can be estimated only by the analysis of specimens, whose characteristic appearances do not indicate any degree of alteration.

* Poggendorff's Annalen, lxxviii, 319, et seq.

† German edition, ii, 253 et seq., 279 et seq.

‡ English edition, i, 36.

It is a generally received opinion among mineralogists, that minerals which are imbedded in others or seated upon them, are either of simultaneous origin with these, or have been formed subsequently by infiltration, as, for instance, calc-spar. But there is no question that many minerals occurring in this manner have been formed by the alteration of those in or upon which they are found, and this is especially the case in fissures. When hydrated peroxide of iron or calc-spar are associated with minerals, containing silicates of lime, or protoxide of iron, it is very probable that they are products of the decomposition of these minerals by means of atmospheric oxygen or carbonic acid* and water, especially when the minerals do not present that sharpness and perfect character which is proper to them in their normal state. If hydrated peroxide of iron and carbonate of lime had been brought and deposited by water in this case, they would be found in other minerals which may be situated at the same place, and which do not contain any protoxide of iron or lime. But there is probably no instance in which felspar, mica or quartz effervesces with acid, however much the wernerite imbedded in the granite may effervesce, and we might expect this would be the case if the carbonate of lime had been deposited from water. Nothing can be more obvious than the inference, that when wernerite effervesces with acid, it is because the silicate of lime that constitutes part of this mineral has been converted by atmospheric action into carbonate of lime, but that felspar, mica and quartz do not effervesce, because they do not contain the silicate of lime from which carbonate of lime may be formed in this way.

In addition to the phenomena by which the above view is shown to be true,† I may add that the greater number of rocks containing silicate of lime effervesce with acids even when there is no alteration perceptible mineralogically, and that this effervescence with acids is greater in proportion to the degree of alteration the rock or mineral has undergone. Therefore the presence of carbonate of lime in these rocks cannot be ascribed to deposition by water, but to the greater or less decomposition of the silicate of lime by carbonic acid.

When the carbonate of lime, originating from the decomposition of silicate of lime, crystallizes, it appears interwoven with those minerals of the rock which have not suffered alteration.

* English edition, i, 2.

† Ibid. 10.

Formerly, when the decomposition of minerals by atmospheric influences, and the phenomena of pseudomorphism were not known, and when the fact that calc-spar might crystallize from calcareous water was disregarded, interwoven minerals could only be regarded as of simultaneous formation. But if the phenomena of artificial crystallization had been at all studied, it would have been evident that minerals are formed by processes very different from those which are commonly supposed to take place.

Geologists are now unanimous in the opinion that the formation of crystalline minerals, whatever may be their origin, has taken place very slowly. In the laboratory, crystallization serves as a means of separating different substances in solution, since crystals in forming do not include anything heterogeneous, excepting some of the mother liquor, and that may be separated by repeating the crystallization. Whatever is known of the genetic history of crystallization is derived solely from laboratory observation, and it is by this alone that we can be guided in attempting to trace the origin of crystalline minerals. Now as it is known that when crystallization is effected rapidly, heterogeneous substances are separated; there seems to be no possibility of supposing that in the very slow crystallization of minerals, the opposite result should be produced; that notwithstanding the long continuance of the liquid state which afforded opportunity for the separation of mixed substances, still heterogeneous substances were separated in an individual form.

When a mineral is interwoven with another, and also occurs as a pseudomorph after the latter, it is very probable that there has been a conversion of the one into the other. It should then be ascertained whether there are any signs of the crystalline form or cleavage of the mineral constituting the matrix. Thus, at Kragerö, asbestos occurs interwoven with hornblende,* and the cleavage planes of the latter may be detected within certain limits, upon the exterior faces of the former mineral, or the crystals separate into laminæ, which become thinner until they appear as silky flexible threads of greenish asbestos, while the crystal faces of the original hornblende is retained.

However, I am by no means of opinion that minerals which are interwoven with others, have, in all cases, originated by alteration of the latter. It cannot be supposed that mica, chabasite, or galena imbedded in quartz crystals have been formed by the alteration of silica. These imbedded minerals were the nuclei

* See chap. xxxvi.

around which the deposition of silica took place in the same way that urinary calculi are formed in the bladder of an animal.

It will be shown in chapter xxxv, that, at different parts of a crystal, the composition may vary; there are only two ways of accounting for this fact: either the crystal was originally formed with this difference of composition, or it has undergone alteration since it was formed. As the formation of large crystals of substances that are very sparingly soluble in water requires a very long time, it is possible that there may at some time have been a change in the material from which they were formed. Thus, as crystallized felspar, for instance, contains different quantities of potash and soda, a dissimilarity might in this way arise in the same crystal, if its formation extended over a very long period. But when the oxygen quotient is found to vary at different parts of the same crystal of felspar, there can be no doubt that it is the result of subsequent alteration. The latter case is probably the more frequent.

Formation of Silicates.—By the decomposition of compound silicates by means of water, carbonic acid, and oxygen, simple silicates are produced; but only those remain intact, the bases of which do not form carbonates, so that the products of such decomposition are principally silicates of alumina which form a part of most compound silicates. They occur as clay and kaolin more or less pure, and in large quantity, but always combined with water, which, when the silicates they originate from were anhydrous, has been taken up during the decomposition. The occurrence of alkaline silicates in water, shows that in this decomposition they are separated undecomposed to a great extent. This is consistent with the chemical relation of carbonic acid and alkaline silicates.*

The frequent occurrence of hydrated protosilicate of iron in water and in minerals† leaves no doubt that it is, for the most part, separated in the decomposition of compound silicates. This may be conjectured to occur when the water which effects the decomposition does not contain oxygen. It may with good reason‡ be assumed that the carbonic acid present in water does not always effect the decomposition of protosilicate of iron, but only under certain conditions. The same is true of silicate of manganese.

Among the silicates whose bases form carbonates, the silicates of magnesia are generally separated unaltered, and not as

* English edition, i, 2.

† Chapter xxvi.

‡ English edition, i, 4.

carbonates in the decomposition of compound silicates.* The slight decomposition of silicate of magnesia by means of carbonic acid,† sufficiently accounts for this circumstance, and it is likewise proved, as will be shown subsequently, by the frequent occurrence of pseudomorphs, consisting wholly, or for the most part, of silicate of magnesia, after minerals which contain silicate of magnesia.

The silicates of lime, a base which is in many respects so similar to magnesia, present a different relation to carbonic acid, and are generally converted into carbonates in the decomposition of compound silicates. It is probable that only the minute quantity of silicate of lime present in the water of some springs has escaped the action of carbonic acid in the decomposition of compound silicates.

In the alteration of rocks containing silicate of lime, especially those in which the proportion is large, such as basalt, dolerite, melaphyre, etc., considerable quantities of silicate of lime are continually converted into carbonate which is partly deposited in drusy cavities, and partly carried into the sea. Hence arises the question whether there is not any process by which silicate of lime may be reproduced.

If limestone exists together with quartzose rocks at those parts in the interior of the earth from which lava originates, the formation of silicate of lime may reasonably be supposed to take place; for at a red heat carbonate of lime in common with all other carbonates is decomposed by silica, and thus silicate of lime as well as other silicates may be formed by fusion at or in the neighbourhood of volcanic foci.

Carbonate of lime and other carbonates are decomposed by silica even at 212° F.‡ Therefore silicate of lime may be formed from carbonate of lime at the places whence boiling springs originate. The frequent occurrence of carbonic acid exhalations indicates a very general process by which this gas is produced, and if it should prove that the decomposition of carbonates by silica contributes to the production of this gas; the continuous formation of silicates in the interior of the earth may easily be understood.

But silicate of lime is also formed in the wet way by the reaction of sulphate of lime or chloride of calcium with alkaline silicates,§ or silicate of alumina.||

* Chap. xxvi. † English edition, i, 2, and 3. ‡ Ibid. 7 and 237.

§ Ibid. 11.

|| Ibid. ii, 68, No. 43.

The water of springs may contain alkaline silicates,* chloride of calcium,† and sulphate of lime. Since the quantity of the latter salt present in the water of rivers falling into the sea is exceeded only by that of carbonate of lime,‡ it follows that on the average it will be present in the greatest amount in the water percolating rocks.

The silicates of alumina are the most frequent of all the mineral silicates, and are components of those minerals and substances which constitute the principal part of crystalline and sedimentary rocks. Consequently they are the principal constituents of the clay resulting from the alteration of these rocks, and wherever water containing sulphate of lime or chloride of calcium, comes in contact with silicates of alumina, there is a possibility that silicate of lime may be formed.

The reality of any chemical process of mineral alteration becomes more evident in proportion as it is possible to recognize the occurrence of all the products of the reaction. Alumina is one of the most unfrequent substances in the water of springs, and is never present in more than very minute quantities. However it would be found more frequently if the peroxide of iron obtained in analysis were tested carefully. It has been detected in the water of several rivers though in very minute quantity.§ The state of combination of alumina in water cannot be determined. The brine XII|| contained a considerable quantity of sulphate of alumina. Of course this salt could not exist in the water of springs containing alkaline carbonates.

Sulphate of alumina occurs in aluminite, hair-salt, potash-, soda-, ammonia-, iron-, manganese-, and magnesian-alum, and in pissophane. These substances are in many instances, particularly in brown coal beds, alum-shale, etc., products of the decomposition of iron pyrites and clay; but there is little probability that the sulphate of alumina occurring in clay-slate, trachyte, micaceous schist, felspathic porphyry, etc., originated in the same manner. It is more probable that it is a product of the decomposition of silicate of alumina by means of gypsum. Moreover, it is only under particularly favorable circumstances that a substance so soluble as sulphate of alumina would be deposited.

Alkaline carbonates and carbonate of lime precipitate hydrate

* English edition, i, 11, and chap. xxvi. † Ibid. i. 344. ‡ Ibid. 81.

§ It can be regarded as dissolved in river-water only when the water has been most carefully filtered previous to analysis.

|| English edition, i, 370.

of alumina from solution of sulphate of alumina.* The contact of this sulphate, which is the only soluble aluminous compound that has been detected in water, with the above-mentioned carbonates, would account in the simplest manner for the formation of native hydrate of alumina. Whether the decomposition of sulphate of alumina were effected by alkaline carbonates, or by bicarbonate of lime, the resulting sulphates would be removed by water. Since alkaline sulphates together with alkaline carbonates occur in the water of many springs, and sulphate of lime together with carbonate of lime occur in the water of many others, it is possible that in many instances these sulphates may have originated from such decomposition of sulphate of alumina by carbonates. At least, there is no objection to the opinion that the native hydrate of alumina is formed in the manner above described.

Silicate of magnesia is formed by the decomposition of sulphate of magnesia, or chloride of magnesium,† from silicates of lime‡ and alumina;§ by the decomposition of bicarbonate of magnesia by means of silicate of lime,|| or by the decomposition of silicates of potash.¶

Chloride of magnesium occurs in the water of many springs,** and the formation of silicate of magnesia may take place by the action of such water upon silicate of alumina, in the form either of clay or compound silicates. The minute quantity of chloride of aluminum that would be produced by this reaction, cannot readily be detected in the water of springs; but it is worthy of notice that a considerable quantity of this salt has been found by three chemists in the water of the Dead Sea.†† The large amount of sulphate of magnesia in the water of many rivers,‡‡ admits of the opinion that this substance is equally abundant in the water percolating rocks, and it is known to be present in the water of many springs. Consequently, the conditions for the formation of silicate of magnesia from silicates of alumina would, in that case, obtain.

Near Kassoibrod in the Ural,§§ diaspore and mica occur in small lodes in chloritic schist, and near Achmatousk, in the Ural,||| hydrargillite occurs in micaceous schist. It is not improbable that a portion of the silicate of magnesia in these chloritic and

* English edition, ii, 69.

§ Ibid. 69, No. 44.

** Ibid. i. 344.

§§ Fiedler—Poggendorff's Annalen, xxv. 322.

||| G. Rose.—Reise nach dem Ural, ii, 122.

+ Ibid. i, 11.

|| Ibid. i, 13.

†† Ibid. i, 92.

‡ Ibid. ii, 67, No. 41.

¶ Ibid. ii, 69, No. 46.

‡‡ Ibid. i, 82.

micaceous schists, in which hydrate of alumina occurs, is a product of the decomposition of silicate of alumina by chloride of magnesium or sulphate of magnesia. If the aluminous salts thus formed came in contact with water containing bicarbonate of lime, or with calc-spar, hydrate of alumina would be precipitated. The occurrence of diasporé in agalmatolite, which is almost pure silicate of alumina, favours the view that this hydrate of alumina is formed in this manner.

The occurrence of anhydrous alumina, as sapphire in basalt, or corundum in gneiss and granite, warrants the assumption of a similar mode of formation, the more so, as the occurrence of pure alumina in rocks, which, besides silicates of alumina, do not contain any other compound of this earth, can only be ascribed to the decomposition of these silicates. In any case this view will have the greater degree of probability so long as no other mode of decomposition of silicates of alumina are known, and it is only when iron pyrites occur in the neighbourhood of the hydrated or anhydrous alumina, that the decomposition of silicate of alumina can be supposed to have resulted from the formation of sulphuric acid, or the precipitation of alumina from the sulphate of alumina thus produced, to have been effected by carbonate of lime or alkaline carbonates.

The occurrence of emery finely disseminated throughout the chloritic schist in which diasporé occurs,* as well as the presence of a small quantity of corundum† in this schist, show that there is such a relation between hydrated and anhydrous alumina, that the latter has probably originated from the former.

Among the magnesian salts, the bicarbonate of magnesia is the one most frequently present in the water, both of mineral and fresh springs. Such water may decompose the calcareous and alkaline silicates in compound silicates, and give rise to the formation of silicate of magnesia, while quartz would be formed at the same time.‡

Since chloride of magnesium, sulphates of lime and magnesia, are next to chloride of sodium, the chief constituents of sea water, while silicate of alumina is present, partly in suspension and partly at the bottom; the conditions for the formation of calcareous and magnesian silicates are highly favorable. But as

* G. Rose—loc cit, i, 248. Fiedler found some fragments of diasporé in emery, consisting of granules of corundum.

† Ibid. 151 and 256.

‡ English edition, ii, 69, No. 46. ~

chloride of aluminum, as well as sulphate of alumina, is decomposed by bicarbonate of lime, it is impossible for these aluminous salts to exist together with this carbonate, either dissolved in sea water or in a solid form at the bottom of the sea, and by their reaction there would be formed sulphate of lime or chloride of calcium, while alumina would be separated in the state of hydrate.

As chloride of calcium is not present in sea water, it is only the sulphate of lime that would give rise to the formation of silicate of lime. In addition, therefore, to the process already mentioned, by which the sulphate of lime, carried into the sea in such large quantity, is decomposed;* there is another by which the quantity of this substance in sea water is not diminished, but even increased, at the cost of magnesian salts.

The importance of silicate of alumina as a means by which the decomposition of the sulphate of lime in sea water is effected, becomes greater in consequence of the circumstance that it also gives rise to the formation of silicate of magnesia by the decomposition of the chloride of magnesium in sea water. Consequently, silicate of magnesia and silicate of lime, may be formed in the masses of clay at the bottom of the sea, and are actually formed as is shown by the investigation of the deposits under Amsterdam, which have undoubtedly been deposited from the sea.† The analyses of these deposits show the presence of magnesia, which is in the state of silicate, and amounts to from 3.05 to 5.19 per cent. It is not to be supposed that the silicate of lime found in these deposits was conveyed there suspended in the water of rivers. Even when silicate of lime, which is so readily decomposed, is carried into rivers, it would, within any long distance that it was carried by water in a state of fine division, be decomposed by the carbonic dissolved in the water, or by the atmospheric carbonic acid, and converted into carbonate of lime, while the silica was separated. The former would certainly be dissolved, the latter probably. Therefore, the silicate of lime in these deposits are unquestionably of recent formation, and if we were not acquainted with processes by which it might be formed, we should be compelled to infer that there were such processes. It is worthy of notice that the quantity of silicate of magnesia in these deposits is throughout greater than that of silicate of lime. This relation might have obtained in the formation of these substances, as is

* English edition, i, 103.

† P. Harting. *De Bodem onder Amsterdam*, 1852.

probable from the above-mentioned circumstances, according to which, silicate of magnesia would have been formed in greater proportion than silicate of lime, or it may be owing to an actual deposition of silicate of magnesia, for since it is so much less readily decomposed than silicate of lime, it may be carried for long distances by rivers without undergoing any great degree of decomposition.

The reactions that have been treated of, show that there are a variety of processes by which the carbonate of lime in marine deposits, may be converted into silicate of lime. The carbonate of lime in the deposits under Amsterdam, appears therefore as the remainder which has hitherto escaped this alteration. The quantity of alumina in marine deposits is not diminished by these processes, for only a portion of the silicate of alumina is converted into hydrate of alumina. Indeed the fact that mineral silicates are only partially decomposed by other acids than concentrated sulphuric acid, renders it probable that they are mixtures of silicate and hydrate of alumina, as many chemists are disposed to regard them.

It would be very illogical to suppose that the calcareous and magnesian salts dissolved in sea water, do not take part in chemical alteration, when it is so manifest that alteration is effected by these salts dissolved in much smaller quantity in the water percolating rocks. It would be inconsistent with the relation of mutual compensation perceivable in all natural phenomena to suppose that saline substances were continually carried into the sea without being consumed in the formation of new minerals.

Decomposition of Silicates.—The decomposition of silicates by artificial means has already been treated of.* The mineral silicates present essential differences with regard to decomposition. It is a very general observation that particular faces of crystals undergo alteration more readily than the others. The principal cause of this difference, probably consists in the circumstance, that the substance of a crystal is more liable to decomposition at those faces which form angles with the planes of cleavage, than at those faces which are parallel with those planes; for in the former case there is much more opportunity for the penetration of water. This relation is on a small scale similar to that presented upon a large scale by the slate rocks, which decompose more readily when the planes are inclined and exposed at one end to the atmosphere, than when they run horizontally. In the same manner, imperfectly

* See ante, p. 82.



developed crystals with rough striated or drusy surfaces would be more liable to decomposition than perfect crystals.

The silicates that are most readily decomposed, are generally those containing lime, protoxides of iron and manganese, and those which contain these bases in greatest proportion are most easily and rapidly decomposed. Minerals consisting chiefly of silicates of alumina and magnesia which are the most stable of the silicates, are less liable to decomposition, for silicate of alumina is not at all affected by carbonic acid and silicate of magnesia very slightly.* However corderite and olivine are exceptions to this rule.

The silicates which are least liable to decomposition are chiefly such as have originated from the alteration of the less stable silicates, as is shown in many instances by pseudomorphs, so that they may be termed the final products of alteration. They are not liable to undergo any further alteration by means of the atmospheric agents, water, oxygen, or carbonic acid; they may be either compound or simple silicates—mica, chlorite, serpentine, asbestos and amianthus; steatite, talc, silicate of alumina, clay and kaolin.

The most remarkable product of mineral alteration is unquestionably mica. In point of perfect development, there is no compound mineral that can be compared with it. In lustre and cleavage it exceeds all others, and it is scarcely inferior to any in stability. It is for this reason that while it occurs pseudomorphous after a great number of minerals, there are only two minerals—steatite and hornstone—which occur as pseudomorphs after mica.

Mica, perfectly unaltered, occurs associated with minerals that are entirely decomposed. Its great stability is the more remarkable, since there is no other mineral that has such a perfect cleavage, and the more perfect the cleavage of a mineral, the more easily it may be penetrated by water and exposed to the influence of decomposing agents. A tabular crystal of mica resembles a book, the individual laminæ adhere to each other scarcely more than the leaves, and by inserting a knife-blade between them there is only their adhesion to overcome. There is sometimes an incrustation upon the edges of the laminæ of mica which joins them together, and presents some obstacle to the cleavage in a manner similar to the gilding on the edge of a book.

When the layers of a highly micaceous mass of gneiss are much inclined, meteoric water penetrates into it with ease, and the

* English edition, i, 2 and 3.

circumstances are most favorable to decomposition, but the mica is rarely altered.

I have estimated the thickness of laminæ of mica from their superficies and weight, then split them so long as it was possible until the laminæ were only 0·00016 or 0·00003 of a line in thickness, and still the limit of cleavability was not reached, as could be seen when these thin laminæ were examined under the microscope; for when the rays of light fall upon them at an angle they present either spots like bladders of a white colour, and formed by adhering laminæ, or irregular curved lines forming the outline of laminæ. Frequently several of these curves appear concentric owing to the superposition of several laminæ. Moreover the concentric colored rings presented by laminæ of mica, upon which light falls at an angle, indicate interstices, and consequently adherent laminæ. The limit of cleavage cannot therefore be ascertained, and there is probably no impossibility in Hauys' calculation, that a lamina of mica might be only $\frac{1}{800000}$ of a line thick.* This is even thinner than the gilding upon lace which Reaumur found to be $\frac{1}{300000}$ of a line thick.

There can be no doubt that water penetrates between even the minutest laminæ of mica. Very thin laminæ of the fine mica of Aschaffenburg, appear when freed from the flesh colored dust with which they are generally covered, but slightly transparent. When split the same dust is found on the fresh surfaces, and when separated the transparency of the laminæ is found to be greater, and to increase upon further splitting of the laminæ. However it is not always possible in this way to obtain perfectly transparent laminæ, and so long as there are opaque spots there are planes of cleavage and dust between them. This dust can have been introduced only by water, for if it were a product of the alteration of the mica, the surfaces upon which it lies would appear disintegrated, or at least they would have lost their lustre. They do not, however, present the slightest alteration. When such a plate of mica is acted upon with hydrochloric acid, the dust is dissolved, and it becomes more transparent while the solution is found to contain peroxide of iron, alumina, lime and magnesia, so that the acid must penetrate between even the most strongly adherent laminæ in the same way that the water did.

It is very remarkable that a mineral should, under these circumstances, be so little liable to decomposition; for supposing the laminæ of mica to be $\frac{1}{800000}$ of a line thick, a cubic inch would

* English edition, i, 60.

have a surface of 150,000 square feet.* Compared with such an extent of surface the mass is insignificant.

These remarks are applicable not only to mica, but likewise to all the other compound silicates which are final products of alteration, and it is very remarkable that among these, chlorite and talc are characterized by their perfect cleavage. So likewise asbestos and amianthus, which are products of the alteration of augite and hornblende, are characterized by their extreme divisibility into delicate fibres, and these minerals are stable only because they are the remainders of others from which everything liable to alteration by atmospheric agents, has been separated.

The minerals, containing silicates which are not decomposed by carbonic acid, are not the only final products of alteration, there are, besides these, quartz in its various modifications, oxides, hydrates, and carbonates incapable of higher oxidation.

The cyclical character which is so generally recognizable in the alteration of minerals suggests the question whether these last-mentioned minerals which have been spoken of as final products of alteration, may not really be particular stages of wider cycles of alteration. It is certain that there is a limit to their duration; those among them which are characterized by so slight a degree of solubility, as to be justly regarded insoluble—silicates of alumina and magnesia, oxide of iron, hydrated oxide of iron and quartz, are the most stable. It is very probable that the silicates of alumina and magnesia may, under certain conditions, become the starting points of other metamorphic processes. Andalusite which, as a simple silicate of alumina, may be a product of the alteration of felspar, is capable of conversion into mica, steatite and talc. If the silicates of magnesia were dissolved and carried away by water, they would also take part in the formation of new minerals. There are likewise means by which peroxide of iron and quartz may be again brought within the cycle of alteration. Oxide of iron is reduced by organic substances, and thus becomes soluble. By means of organic substances and sulphates, oxide of iron may be converted into iron pyrites which, being liable to further alteration, may furnish material for new products. The disintegration of quartz is facilitated by moss and other plants; the pseudomorphous and corroded quartz show that this form of silica may be dissolved, and the siliceous substances formed by infusoria show that organic agency is capable of effecting transformation of this substance. The inorganic substances in plants and

* English edition, i, 60.

animals, the growth of plants on land and in the sea, show that organic agency has a share in the alteration of minerals.

Although the simple silicates are, for the most part, products of the decomposition of compound silicates which existed previously, I shall enter upon the consideration of the simple silicates in the next chapter. Then follow the compound silicates, and, in the first instance, those which do not occur in the forms of other minerals and have, therefore, been formed directly. Lastly come the compound silicates which are frequently pseudomorphous, and may, therefore, be products of the alteration of many other minerals without being so in all instances, since the occurrence of many of them indicates a direct mode of formation. The silicates forming the intermediate members of this series will be treated of in such order that the description of a silicate B which occurs pseudomorphous after another silicate A will follow the description of the latter. Undoubtedly this method cannot be strictly followed out; because, in some instances, A may likewise occur pseudomorphous after B. Moreover, the arrangement may be liable to alteration, in consequence of the further discovery of pseudomorphs. Some seven years since felspar would have been placed in the first part of the series of silicates, because it was not then known that this mineral occurred in a pseudomorphous state. A chemical classification of minerals unquestionably requires that the knowledge of a mineral should precede that of the products of its alteration. Since, for example, laumontite and analcime, are both convertible into felspar, they must be treated of before the latter.

Silicates that occur in spaces which were originally empty can have been formed only from their constituents for these spaces were impervious to everything but water solutions. Drusy cavities are such empty spaces in rocks; we are enabled to examine them throughout, and to certify ourselves that they are either perfectly closed or have only such a minute opening at one point as to admit water, so that there is no case in which the direct formation of silicates may be so decisively proved as in that of zeolites occurring in drusy cavities. It would indeed seem as though these minerals could be formed only in a direct manner, for so far as we yet know the formation of natrolite from nepheline is the only contrary instance.*

For the reasons above given, I shall commence the consideration of compound silicates with the zeolites.

* Blum, 2^{ter} Nachtrag zu den Pseudomorphosen, p. 132.

CHAPTER XXVI.

SIMPLE SILICATES.

THESE silicates are of much less geological importance than compound silicates because they occur much less frequently than the latter.

A.—*Alkaline Silicates.*

Occurrence.—These silicates do not occur uncombined as minerals owing to their great solubility. They occur only in water, and in very minute quantity. However, in combination with other silicates, they constitute a large part of the compound silicates which are of most frequent occurrence.

The presence of alkaline silicates in the water of springs has been fully proved. Forchhammer* found silicate of soda in the water of the Geysers and of Laugarness in Iceland.

The inorganic constituents of plants show that silicates are present in the water which permeates the soil, and which supplies plants with their nutriment.†

* Poggendorff's Annalen, xxxv, 348.
† Ordinary potash contains silica combined with potash. Perhaps this silicate of potash originates, in part, from the decomposition of carbonate of potash by silica in the incineration of the plants, but some of the silicate certainly existed in the plants as silicate of potash or of alkaline earths.

In grasses we find silicate of potash that is conveyed to them by irrigation. The *equisetaceæ* and reeds which contain such large quantities of silica, or silicate of potash, flourish in greatest luxuriance either in ditches and brooks where, from the frequent change of water, the supply of silica is maintained, or on clay soils rich in potash and on marshes.

The quantity of silicate of potash annually removed from a meadow in the hay is very considerable. I have found the silica in hay amount to 2·068 per cent. After a thunderstorm, there was found in a meadow between Mannheim and Heidelberg, a glassy mass, consisting of silicate of potash, upon the spot where a hay-rick had stood, that was struck by lightning.—Liebig, *Agricultur Chemie*, p. 165. Although the potash in this mass may not have existed in the hay wholly as silicate of potash, but partly in combination with organic acid, there can be no doubt that there was some silicate of potash present.

The analysis of the ash of wheat-straw by Fresenius will serve as an example. Ibid. p. 329.—

Potash combined with silica	....	....	14·09
Lime	”	”	7·62
Magnesia	”	”	1·92
Silica	....	....	63·89
			—
			87·52
Remaining salts of potash, lime, and magnesia			10·48

The potash, alkaline earths and silica make up 87·52 per cent. of the salts present.

I 2

B.—Silicates of the alkaline earths.

Since silicate of lime dissolved in water is decomposed by carbonic acid,* it might be supposed that the water of acidulous springs, which is saturated with carbonic acid, does not contain silicate of lime, and on this account could not contribute to the formation of zeolites, or any minerals containing silicate of lime. However, according to Kersten, the mineral water of Marienbad deposits silicate of lime, together with silicate of magnesia, when evaporated.†

The water of the Kochbrunnen at Wiesbaden, also deposits silicate of lime.‡ When rocks, such as labradorite, are decomposed by water accompanied by currents of carbonic acid, it would appear that the lime is separated only as bicarbonate. Hence, in the drusy cavities of amygdaloid rocks, zeolites are found only when there is an opportunity for the solution of silicate of lime by fresh water. The frequent occurrence of calc-spar in these drusy cavities shows that even in this case carbonate of lime is formed.

The possibility of the existence of silicate of magnesia in the water of acidulous springs cannot be doubted, because this substance is not decomposed by carbonic acid.§ The great tendency of magnesia to the formation of double salts, renders it probable that silicate of magnesia in the water of springs of this kind may be combined with carbonate of magnesia. The existence of such

According to my analysis, the silica in the straw alone, amounts to 2·161 per cent.

Neither potash, lime, nor magnesia, exist in soil in a free state; and as the amount of bases required by the phosphoric and sulphuric acids and chlorine have been deducted in the above analysis, the remainder can only be combined with carbonic acid or silica. If bases pass into plants as carbonates, they would undoubtedly be decomposed by the organic acids, and the carbonic acid thus liberated would, like all the carbonic acid taken up by plants, be decomposed under the influence of solar light. If the bases pass into plants as silicates, these also would be decomposed in part by the organic acids, and the silica separated would partly remain dissolved in the sap and partly be deposited. But by incineration, the organic acids are decomposed and carbonic acid formed from them, which, like the silica, enters into combination with the bases. Hence, we find that potash contains silicates together with carbonates. In the ash of the straw, however, silicates alone were formed by the incineration; and the great quantity of silica present shows that it was undoubtedly introduced into the plant in the state of silicates. Although the analysis of plant ashes will not furnish any certain indications of the mode of combination of the acids and bases in plants, or even in the soil, there still can be no doubt that soluble silicates pass from the soil into plants.

* English edition, i, 2, No. 1, b.

‡ Ibid. 151.

† Ibid. 5.

§ Ibid. 2, No. 1 c.

compounds in quartzose-magnesite—giobertite,—might be regarded as favorable to the opinion that they exist in carbonated water. But from a geological point of view, this is of very slight importance; because the highly carbonated water of some springs is far less generally the agent by which rocks are altered, than the water containing merely minute quantities of carbonic acid derived from the atmosphere and the soil.

Alkaline silicates may exist in the water of carbonated springs.* There can be no doubt that silicate of alumina may exist in water saturated with carbonic acid, because there is no carbonate of alumina. The minute quantity of alumina sometimes found in mineral water undoubtedly proceeds from silicate of alumina. The existence of protosilicate of iron in carbonated water is equally possible,† and it is moreover found in the deposits from the water of springs.

The water of fresh springs may contain any of the silicates in solution. The individual consideration of these silicates will show that those of the alkaline earths are not nearly so insoluble as is generally supposed. The solubility of artificial hydrated silicates of lime and magnesia does not indeed afford any indication of the solubility of the native anhydrous silicates of these bases; but it has already been shown that by the prolonged action of water, silicates that may be insoluble take up water and, becoming hydrated, pass into the condition of the hydrated silicates obtained artificially. Both hydrated and anhydrous silicates present different quantitative relations between the acid and bases, and the different hydrated silicates of any one base may differ in solubility. However, this is no objection to the view I have put forward, because the situation of these silicates shows decisively that they have been deposited from water, and must, therefore, have been soluble at the time of their formation.

Moreover, the degree of solubility of any substance is, from a geological point of view, unimportant. If it is not absolutely insoluble, no objection can be raised against the opinion that minerals which consist of it have been formed in the wet way. The least soluble substances will require a greater amount of water for solution, and, under circumstances otherwise similar, the minerals consisting of them will be formed more slowly than those consisting of more soluble substances.

The reactions described already, have made us acquainted

* English edition, i, 2, No. 1.

† Ibid. 4.

with several possible modes by which silicates may be formed in the wet way. At a red heat, and even at 212° F., they are formed from carbonates by reaction with silica. Silicates of the earths and of metallic oxides are formed by the reaction of such of the salts of these bases as are soluble in pure or carbonated water, with alkaline silicates.*

These reactions likewise point out various decompositions of silicates by simple or double affinity. To the former kind belong the decomposition of the silicates by carbonic acid; to the latter, the decompositions of silicates by various substances occurring in water, &c. Thus, silicate of lime is decomposed by alkaline carbonates, bicarbonate of magnesia, alkaline fluorides, sulphate of magnesia, chloride of magnesium, and by hydrated sesquioxide of iron; silicate of alumina is decomposed by sulphates of lime and magnesia, chloride of calcium and magnesium, by hydrated sesquioxide of iron, and by alkaline fluorides; persilicate of iron is decomposed by sulphate of magnesia and by chloride of magnesium; silicate of magnesia is decomposed by hydrated sesquioxide of iron and by alkaline fluorides; alkaline silicates by hydrated sesquioxide of iron, bicarbonates of iron, and magnesia, aluminate of magnesia, and by borate of lime; silicate of potash by chloride of sodium, and silicate of soda by carbonate of potash.

It is probable that further research will make known a still greater number of processes by which silicates may be formed or decomposed.

The experiments of v. Kobell† upon the precipitation of silicates from solution in hydrochloric acid, by carbonate of lime have no geological interest.

We now come to the consideration of the simple silicates occurring as minerals. Although the existence of silicates of baryta and of strontia is highly probable, it has not been ascertained with certainty. The artificial silicates of these earths have already been treated of.

C.—*Simple silicates of lime and magnesia.*

Of the two classes of silicates comprised under this head, the magnesian silicates are very abundant and frequent, while the calcareous silicates occur only in a few minerals.

Silicates of magnesia.—The frequent occurrence of pseudomor-

* English edition, i, 6, et seq., Nos. 3, 5, 8, 9, 10, 11, 16, 17, 18, 23, 24, 25.
† Schweigger's Journal, lxiv, 297.

phous steatite and talc shows that the simple silicate of magnesia, originates to a great extent from the alteration of compound silicates. There is not a single instance of the occurrence of pseudomorphous silicate of lime, such as wollastonite after a compound silicate or any other mineral. The reason of this is evident when we remember that in the alteration of compound calcareous silicates, it is with few exceptions the silicate of lime that is first decomposed, and for the most part removed in the state of carbonate. On the contrary, in the alteration of compound magnesian silicates, the silicate of magnesia is never decomposed first, and, as we have seen already, is rarely decomposed at all. Again, the pseudomorphous steatite presents the forms of all those minerals which are known to contain silicate of magnesia, while all the other silicates have disappeared. It is, therefore, to the different chemical relations of the silicates of lime and magnesia to the conditions under which compound silicates are decomposed, that we must ascribe the entire absence of the former, and the frequent occurrence of the latter, in the forms of other minerals.

Solubility.—Silicate of magnesia, prepared by precipitation from solutions of silicate of soda and of sulphate of magnesia mixed with chloride of ammonium, is more soluble than the ammonia-phosphate of magnesia, for basic phosphate of ammonia produces a distinct turbidity in the solution. The silicate of magnesia was washed until chloride of barium no longer produced any precipitate in the filtrate, and in three experiments it was found that the silicate dissolved in

32,376	parts of water :
46,400	” ”
90,600	” ”

The great affinity of magnesia for silica,* or, at least, the tendency of the two to be precipitated together from solution, is doubtless, owing to the sparing solubility of the silicate of magnesia, and the fact that, in the analysis of minerals containing magnesia, a large part of the silica is dissolved with the magnesia, and afterwards

* It is seldom that great accuracy can be attained in determining the solubility of such substances as silicate of magnesia, which are so sparingly soluble because the quantity of residue obtained by evaporation of even very large quantities of the solution is so minute that a very delicate balance is requisite in order to weigh it correctly. It may, however, be conjectured, that the great discrepancy of the above results may have been occasioned by a difference in the degree of dessication of the silicate of magnesia, or by the shaking of the liquid containing the silicate having been continued longer in one instance than in the others.

precipitated with it likewise indicates the tendency of these substances to combine.*

Occurrence and formation of Magnesian silicates.—Steatite and talc are the most frequent of the magnesian silicates; meerschaum is more rare; all three are hydrated.† The minerals consisting of magnesian silicates always contain minute quantities of other bases; there is no native silicate of magnesia that is perfectly pure. The purest kind contains 0·9 per cent. alumina, with traces of peroxide of iron. The occurrence of these minerals in drusy cavities, and in fissures, proves as well as the pseudomorphous silicate of magnesia that they have been formed in the wet way.

Among the other hydrated silicates of magnesia—villarsite, picrosphyll, aphrodite—spadaite is remarkable because it occurs intimately mixed with silicate of lime—crystallized wollastonite. Now, since silicate of lime may be decomposed by silicate of magnesia,‡ it is possible that spadaite has originated from wollastonite. Several of these minerals may be double compounds of silicate of lime with silicate of magnesia.

The fact that opal almost always contains magnesia shows that silicate of magnesia is very generally present in water. This earth is also present in the siliceous sinter from the geysers.§

Magnesite containing silica.—The quantity of magnesia in the water of a spring probably never amounts only to as much as would be required for combination with the silica, for the quantity of this substance is always very minute. Therefore the magnesia, which is almost always present in water, must be partly in the state of silicate, partly in the state of carbonate. These two substances have, in many instances been deposited together from solution, as is shown by those varieties of magnesite which contain silica. The fact that magnesite always occurs in serpentine, talcose- and chloritic-schist, in dykes traversing talcose rocks, in metalliferous veins and in clefts, etc., shows that it has been deposited from water.

Doberciner's || analysis of a specimen of marly magnesite, shows that its composition was

Carbonate of magnesia	.... 42·64	{ Carbonic acid	.... 22
		{ Magnesia	.... 20·64
Silicate of magnesia	.... 52·36	{ Silica	.... 19·00
		{ Magnesia	.... 33·36
			—
			95·00

* Berzelius.—Jahresbericht, viii, 218.

† Chap. xli.

‡ See ante p. 66, No. 40.

§ Poggendorff's Annalen, xxxv, 352 and 353.

|| Schweigger's Journ., xiii, 318.

The silicate of magnesia in this instance would be a compound of 1 equivalent silica with 4 equivalents of magnesia, the calculated composition being

Silica.....	1	.....	18·79
Magnesia	4	.....	33·57
			<hr/>
			52·36

The results of the analysis of a second specimen of quartzose magnesite do not indicate such a close resemblance in composition, although the composition of the silicate appears the same. There is not in either instance any simple atomic proportion between the carbonate and silicate of magnesia. This mineral has been deposited from water containing bicarbonate and silicate of magnesia, and for this reason their relative proportion is not likely to be fixed; the above remarks are borne out by the very different proportion of silica, varying from 9 to 43 per cent. in the magnesite of Castelamonte, Bandissero, Turin, and of Campo in Elba, analyzed by Berthier,* and by the varying proportion of water, from 1 to 12 per cent. which undoubtedly belonged to the silicate of magnesia.

The magnesite of Piedmont has unquestionably been formed by deposition from water as is shown by the circumstance that it occurs in dykes in a kind of limestone rock. The hard magnesite from Baumgarten in Silesia, analyzed by Stromeyer,† and that from Salem in India,‡ do not contain a trace of silica, and must, therefore, contain carbonic acid enough for saturation of the magnesia. The former mineral contains besides magnesia only 0·2 per cent. of protoxide of manganese, and the latter 0·3 per cent. of lime.

It is worthy of notice that the four specimens of magnesite from the Zillerthal in the Saltzburgh district; from Hall and Fassathal in the Tyrol; and from St. Gothard, which were analyzed by Stromeyer,§ did not contain a trace of silica, but with the exception of a small per centage of protocarbonates of iron and manganese consisted of carbonate of magnesia. These minerals were partly crystallized in perfect rhombohedrons and partly composed of aggregated rhombohedral granules. It is a distinctive character of the siliceous magnesite that it does not occur crystallized, a circumstance which still further favours the opinion that it is not a chemical compound, but a mere mixture of

* Annal. des Mines, vii, 316.

† Schweigger's Journ., xiv, 1.

‡ Karsten's Archiv. iv, 432.

§ Schweigger's Journ. li, 217.

carbonate and silicate of magnesia; protoxides of iron or manganese, may, however, take the place of the magnesia.

Silicates of lime.—While the compound calcareous silicates are very frequent minerals, the simple silicate of lime occurs but rarely and in small quantities.

Solubility.—Artificially prepared silicate of lime is so soluble in water, that oxalate of ammonia produces in the solution a somewhat considerable turbidity. The solution is not rendered turbid by carbonic acid, because bicarbonate of lime is formed, which is more soluble than the silicate, and also because the silica separated is retained in solution. When ammonia is added to the solution through which carbonic acid has been passed, and the bicarbonate thus converted into carbonate, the liquid is not rendered turbid, showing that silicate of lime is not more soluble than the carbonate.

In attempting to estimate the solubility of silicate of lime, the results obtained showed considerable discrepancy arising probably from differences in the degree of dessication. In three experiments the silicate was found to dissolve in

5,383	parts of water
6,882	" "
19,395	" "

Among the artificial silicates of baryta,* strontia,† magnesia,‡ and lime, the silicate of strontia is the most soluble, next to it the silicate of lime, then silicate of baryta, and the least soluble is silicate of magnesia.

The stability of a mineral is inversely proportionate to the solubility of the substance of which it consists; hence the rare occurrence of silicate of lime, and, so far as is yet known, of the silicates of baryta and of strontia. Moreover, when a mineral is readily decomposed by carbonic acid, as is the case with these three silicates, removal by water and subsequent deposition when that water stagnates cannot take place, for in the presence of air these silicates would be decomposed, and the bases converted into carbonates. On the other hand from the relations of solubility and decomposition by carbonic acid presented by the silicate of magnesia, it is intelligible that this substance should occur so frequently in minerals notwithstanding external influences.

Occurrence.—In wollastonite; most frequently in granular limestone, likewise in dolerite, doleritic lava, amygdaloid and in gneiss.

Composition.—It appears that the oxygen quotient of silicate of lime in its normal state, is 0.5, and it is in this state anhydrous.

* English edition, i, 438.

† Ibid. 453.

‡ Ibid. ii, 119.

Besides lime it may contain minute quantities of other bases, alumina, protoxides of iron or manganese and magnesia.

Formation.—The adherents of the plutonic theory regard granular limestone as sedimentary limestone that has been altered by volcanic action; and they would, therefore, suppose wollastonite to have originated in the same way, more especially as it occurs in the masses erupted by Vesuvius.* It has, however, been shown that this opinion is incorrect. When limestone contains silicate of lime, and this is almost always the case, it is easy to understand that water would dissolve this substance and deposit it again in drusy cavities. The minute quantity of carbonate of lime that surface water contains, and which might decompose the silicate of lime would be separated by passing through the limestone so that besides bicarbonate of lime, silicate of lime might be dissolved. It is, however, remarkable that wollastonite occurs only in granular limestone, not in sedimentary limestone where the conditions for its formation obtain equally. Chalk likewise is frequently traversed in all directions by veins of silicate of lime.

The very rare occurrence of silicate of lime compared with that of silicate of magnesia, clearly indicates that the conditions under which the two silicates are formed, are quite different. This difference is to be sought chiefly in the fact that the magnesian silicates are decomposed by carbonic acid only when dissolved in water, while the silicate of lime may be decomposed by this acid, either in the solid state or in solution.†

When meteoric water, containing but a minute quantity of carbonic acid penetrates rocks containing double silicates of lime and magnesia, the carbonic acid acts upon the silicate of lime forming carbonate of lime, which is partly removed by the water, partly left behind. But under these conditions, silicate of magnesia is not decomposed, and either remains unaltered or is removed in solution. So long at least as lime is present it is to be expected that the carbonic acid will combine with it in preference to the magnesia.

Under such conditions carbonate of lime and simple silicate of magnesia would be formed simultaneously; but under other conditions silicate of lime may be removed by water and again deposited. The very rare occurrence of simple silicate of lime and the frequent occurrence of carbonate of lime, in rocks that are passing through this phase of alteration, and in the water of springs rising from them, show that the formation of carbonate of

* English edition, ii, 95.

† Ibid. i, 2, No. 1, b. and c.

lime is invariably the predominating process. When, however, the water of a spring is found to contain carbonate of magnesia together with carbonate of lime, it may be conjectured that the former earth was converted in carbonate only when the greater part of the lime had been removed, or that the silicate of magnesia is dissolved and decomposed simultaneously by the carbonic acid. However, in this case only a minute quantity of carbonate of magnesia would be formed on account of the sparing solubility of silicate of magnesia.

Decomposition.—Some chemists who have examined wollastonite state that it effervesces with acids, some that it does not. As much as 3 per cent. of carbonate of lime has been found in this mineral,* I found that the wollastonite of Orawitza effervesced copiously, and that from Auerbach slightly.

It would follow from these observations that the wollastonite is sometimes intimately mixed with carbonate of lime, either as a product of alteration or from other sources, and sometimes does not contain any such admixture. Those specimens of wollastonite whose oxygen quotient is under 0.5, have undoubtedly experienced a partial conversion into carbonate of lime. It is probable that in some instances the carbonate of lime may have been removed by water from wollastonite that does not effervesce with acids, although the presence of water indicates that alteration has commenced.

Since wollastonite is so readily decomposed by acids, there can be no doubt that it undergoes gradual decomposition, when it comes in contact with water containing only traces of carbonic acid. But when wollastonite occurs in granular limestone, the water percolating the rock loses its carbonic acid by combination with carbonate of lime, and therefore cannot exercise any decomposing influence upon the silicate. When the water contains alkaline carbonates, the wollastonite may be decomposed and alkaline silicate would be deposited in the place of the decomposed silicate of lime. It is true, analyses do not indicate the presence of alkalies in this mineral, but as yet no attempt to test for alkalies has been made. The loss which appears in the statement of many analyses admits of a supposition that the presence of alkalies has escaped notice.

Among other minerals, consisting for the most part of silicate of lime, are, adelforsite, okenite and danburite; the last two are hydrated, okenite containing 17 per cent., and danburite from

* German edition, i, 421.

8 to 10 per cent. of water. The artificial silicate of lime according to my analysis contains 14 per cent. of water.

D.—Simple hydrated silicates of alumina.

Solubility.—These silicates are still less soluble than the magnesian silicates. The silicate of alumina obtained by precipitation from hot solutions of alum and an alkaline silicate, required for solution in two experiments,

334,600 parts of water.
179,050 " "

The occurrence of silicates of alumina in fissures and drusy cavities, as well as the presence of alumina in water, likewise proves the solubility of these substances.

Formation.—As a general rule there can be no doubt that the simple silicates of alumina have originated from compound aluminous silicates by decomposition. Many of them still retain small quantities of other bases. Kaolin and cimolite are the only ones in which crystalline form indicates the minerals from which they have originated. Kaolin occurs with the forms of felspar, porcelain-spar and leucite; cimolite with the form of augite.

Occurrence.—I shall here speak only of those silicates of alumina which occur in fissures, clefts, and drusy cavities, and which, for this reason, can only be deposits from water.

Kaolin is found in beds, nests and veins in granite, and in larger nests in porphyry. It is questionable whether in these situations it has originated from felspar, or has been introduced by water.*

The augite crystals, converted into cimolite, from the district of Bilin, have long been known,† but it was by the analyses of Rammelsberg‡ that we first became acquainted with the process of alteration. These crystals consist of hydrated silicate of alumina, and agree in their composition with cimolite. The considerable quantities of lime and magnesia in the original mineral have, therefore, been completely extracted; appreciable quantities of silica and iron have likewise been removed. The state of combination in which these substances were removed depended of course upon the agent by which the decomposition was effected. Blum shows by the comparison of the density of unaltered augite with that of the cimolite, that there has been a considerable diminution of

* See chapter xxviii. Kaolin, with the form of felspar.

† Blum.—Die Pseudomorphosen, 61.

‡ Poggendorff's Annalen, xlix, 387.

substance in this alteration, and this is likewise evident from the loose coherence and empty spaces in the interior of the crystals. As this augite occurs in basalt, there can be no doubt that it was aluminous. Such a variety of augite would yield 28 per cent. by weight and 67 per cent. by volume of cimolite.*

From the description given by Reuss† of the circumstances under which this pseudomorphous cimolite occurs, there can be no doubt that the agent by which the alteration has been effected, was water containing carbonic acid and oxygen, percolating through the rock from above. This alteration cannot be ascribed to ascending carbonated water, because the dyke has a very considerable thickness. The water must have penetrated between the basalt and gneiss in the first instance, and then spreading into both rocks decomposed them as far as it penetrated. The formation of hydrated substances such as hydrated peroxide of iron, clay, cimolite, &c., cannot be ascribed to any other influence than that of water. There is no question that the decomposition is still in progress, and after a certain lapse of time, the basalt still remaining in the middle of the dyke, will be converted into masses the same as those found between it and the adjacent rocks. Sooner or later the basaltic masses in these dykes will assume the character so frequently observed in basaltic dykes, and be converted into a clayey mass, from which the whole of the lime has been extracted; so that, as I have frequently observed, acids no longer produce effervescence.‡

The greenish colour of the rock and of the augite crystals, leads to the conclusion, that silicate of protoxide of iron, similar to the green earth, is present, together with silicate of magnesia similar to anauxite, both of which must be formed according to Rammelsberg's analyses. The surplus silica of the decomposed augite is found in the compact siliceous masses contained in the dyke. As much of the products of decomposition was removed as would dissolve. Thus the lime may have been removed as carbonate, and the magnesia as silicate.

* See chap. xxxv.

† Die Umgebungen von Teplitz und Bilin, etc., 1840. p. 221.

‡ It is very probable that the basaltic conglomerate which so frequently underlies the basalt, or surrounds the cones like an envelope, may have been formed in a similar manner. The conditions of its formation would be the same as in the above-mentioned dykes. When parts of a rock are decomposed to a greater extent than others, conglomerates will always be formed. We observe this result frequently in basaltic masses; the parts near the surface, which are exposed to the influence of meteoric water, present isolated, roundish nodules, between which the basalt is entirely decomposed into clay, while at other parts, less exposed to the influence of water, the basalt is in a perfectly normal condition.

In the island of Milo sulphuric acid, originating from oxidation of sulphuretted hydrogen, has decomposed the masses of felspar* in a manner similar to that by which the alteration of the augite has taken place at Bilin. At the former place, greater part of the silica of the felspar occurs in a gelatinous state, a smaller part of it as quartz, and this difference is owing to the more powerful decomposing action of sulphuric acid compared with carbonic acid.

If augite were exposed for a long time to the action of sulphuric acid, it might be expected that the alumina would be gradually removed as sulphate. There is no doubt that this has taken place in the decayed augite crystals occurring in a porous, yellowish-white rock, at Vesuvius. According to the analysis of Rammelsberg,† all the bases of the original substance have been removed, so that the silica has relatively increased to the amount of 85 per cent. As to the removal of the alumina from this augite there can be no doubt that in the neighbourhood of the volcano it was effected by stronger acids than carbonic acid.

These remarks on the formation of cimolite, are likewise applicable to halloysite, the occurrence of which in lumps and reniform masses in the diluvial clay at Ecogne, Depart. Ardennes, and in the tertiary strata of Champagne, indicates a similar origin. Pholerite, which occurs in clefts of masses of iron ore, and in sandstone, carboniferous-shale, &c., is nearly related to halloysite. Both minerals have been formed by the decomposition of rocks, probably felspathic, but the decomposition has not proceeded so far as in the case of cimolite, because they both contain more alumina than the latter mineral. Sauvage found in the tertiary strata of Milo, halloysite derived from a felspathic rock by decomposition by sulphuric acid. This mineral contained more quartz and less gelatinous silica than cimolite. Lenzinite, nontronite, tuesite, wörthite, kollyrite, and scarbroite, belong to the same class of minerals; they are hydrated silicates of alumina, which are perfectly decomposed by sulphuric acid, but imperfectly decomposed by other acids.‡ The kollyrite which occurs in dykes in sandstone, upon fragments of drusy cavities in grauwacke, as an incrustation upon ferruginous quartz rocks, contains a greater quantity of alumina than is contained in any other silicates of alumina. Agalmatolite also consists essentially of silicate of alumina.§

* English edition, i, 6, No. 2.

† Loc. cit.

‡ Rammelsberg's Handwörterbuch, p. 211. Suppl. 1, p. 144, and Suppl. 2, p. 150.

§ The analyses of agalmatolite by Klaproth Vanquelin, Thompson, and

While these minerals, consisting of hydrated silicate of alumina, contain no other bases besides alumina, or only very minute quantities, the remaining silicates contain larger quantities of other bases. Thus bole, fat-bole, rhodalite, eisensteinmark, mountain soap, plinthite, contain considerable quantities of peroxide of iron. The first three, occurring in clefts, dykes, and amygdaloid rocks can only be deposits from water. The last two, occurring as beds, appear to be the remains of rocks altered on the spot. Allophane and schrötterite contain some oxide of copper derived partly from deposits of copper ore, and partly from adjacent rocks. Miloschin contains oxide of chromium. Pipe-stone, rosellan, polyargite, figure stone, gilbertite and huronite contain either soda, potash, lime or magnesia.

Sillimanite, steinmark, talcose-steinmark, show that anhydrous silicate of alumina may likewise be formed in the wet way. The occurrence of sillimanite in quartz dykes, traversing gneiss, at Saybrook, Connecticut, and of steinmark in narrow dykes, in metalliferous veins, on the walls of clefts, or in drusy cavities in various rocks, crystalline and sedimentary, leads to the conclusion that these minerals have been deposited from water solutions. As steinmark also occurs in the forms of felspar and topaz, it will be seen that it may have originated from these minerals by alteration. On the other hand, the displacement pseudomorphs of steinmark after fluor-spar indicate its deposition from water while fluoride of calcium was removed.

The anhydrous simple silicates of alumina will be treated of in chapter xxxi.

Lychnell, furnish very different results. Lychnell regards the mineral as a neutral silicate of alumina. A more recent analysis by Karafiat, of the agalmatolite of Schemnitz, agrees very closely with that by Thompson. At the place just mentioned, there occurs another silicate of alumina, called dillnite, which, according to the analyses of Karafiat and Hutzelmann, contains more alumina than agalmatolite. It is found between diorite and limestone, and contains diaspore, iron pyrites and fluor-spar. In different specimens alterations are exhibited, which lead to the conclusion that a concentration of the alumina gradually takes place so that it crystallizes as diaspore. When the mineral appears most pulverulent, the largest, most transparent, and most perfect crystals of diaspore are found.—n. Jahrbuch für Mineralog., 1849, p. 864.

These changes are very interesting, as showing that silica may be entirely separated from silicates of alumina, so that the alumina remains as hydrate. This also throws light upon the very different proportion of alumina in the silicates of alumina, which probably arises from separation of silica and the consequent formation of silicates richer in alumina. The dillnite, a mineral rich in alumina, which occurs at Schemnitz, together with agalmatolite—a mineral containing less alumina—may have originated in this way from agalmatolite. Alterations of this kind, and especially the transition into diaspore, may be supposed to have been effected by water, containing silicate of potash, taking silica from the silicates of alumina.

E.—Simple silicates of protoxide of Iron.

Solubility.—Persilicate of iron obtained by precipitation from solutions of chloride of iron and silicate of soda, and thoroughly washed has a light ochre colour. It requires 105,000 parts of cold water, and 31,401 of boiling water for solution. It is not easily decomposed, and even by long boiling with hydrochloric acid, there is not enough oxide of iron dissolved to give a reaction with ferrocyanide of potassium. This agrees perfectly with the facts stated previously.* Protosilicate of iron occurs dissolved in water.†

Formation.—Proto- and per- silicates of iron are probably, for the most part, products of the decomposition of compound silicates. The following facts furnish evidence in favour of this view.

Occurrence.—Hisingerite, which contains proto- and per-oxide of iron, occurs associated with calc-spar. Pinguite occurs in drusy cavities, in dykes of heavy-spar, in gneiss, in veins of red hematite, and in clefts of basalt. In the latter case the proto-silicate of iron in the basalt has undoubtedly furnished the material. Chamoisite is a mineral of this kind. The fayalite in volcanic rocks appears to be derived from-olivine by decomposition. This is indicated by its containing a small quantity of oxides of lead and copper, the latter being found in olivine likewise.

Several of these protosilicates of iron occur crystallized; such is the case with sideroschisolite, which is found in clefts and drusy cavities in magnetic iron pyrites, together with iron-spar; chlorophaite, in drusy cavities of basalt, together with calc-spar, in drusy cavities of diorite, of amygdaloid, and of porphyry. In the air, it is said to be converted into hisingerite, indicating that the protoxide of iron in the latter has been converted into peroxide, subsequent to its formation. Stilpnomelane, which occurs only in clay-slate, in lievrite, and in a bed of micaceous schist, together with hornblende and quartz, also in drusy cavities in quartz.

All these protosilicates of iron are undoubtedly derived from adjacent rocks, whence they have been extracted by water. Whether the hydrated silicates of iron that contain the iron either wholly in the state of peroxide—anthosiderite, nontronite,—or only partially in that state—hisingerite, sideroschisolite, pinguite,—have been formed directly, or whether the iron has been

* English edition, ii, 71, et seq., Nos. 48, 49, and 50.

† Ibid. i, 4.

subsequently converted into peroxide cannot be determined with accuracy. The remark made with regard to chlorophaite seems to favour the latter view.

Green-earth is a protosilicate of iron. Its green colour shows that it contains protoxide of iron, as well as the analyses, by Hisinger,* of this mineral from the beds of magnetic iron-ore in Dalarne; that by Berthier† of the green granules from the chalk and calcaire grossier; and that of the green sand by Turner‡ and Von der Marck.§ All these substances are silicates of protoxide of iron, alumina, alkalies, &c., and agree in their essential characters with hisingerite—thraulite—chlorophæite, sideroschistite, cronstedite, &c. To this group likewise belong the green colored constituents of clay-slate and sandstones. By chemical examination, the presence of protoxide of iron may be easily recognized. I found it even in variegated sandstone which had no green colour. The change of green colored rocks into brown is owing to a gradual oxidation of the protoxide of iron, and conversion into hydrated peroxide.

The occurrence of green earth in decomposed amygdaloid at Monte Baldo, and in drusy cavities of many basaltic and doleritic amygdaloids, and augitic porphyry, either as an incrustation of the sides of these cavities, or filling hollow stalactites, and forming a coating upon them and upon chalcedony; its frequent occurrence with zeolites, which, as well as bitter-spar, are, in Iceland, frequently colored by green earth, are all facts that speak decisively for its being a deposit from water. Its origin from augite is distinctly shown in places where it occurs with the form of this mineral as in the augitic porphyry of Pozza in the Tyrol, in which the several stages of alteration may be distinctly observed.|| The proportion of alkalies in this altered augite is somewhat considerable, and appears remarkable because augite when unaltered does not contain any alkalies.¶ However, alkaline silicates are present in the labradorite of the augitic porphyry, and since this mineral readily undergoes decomposition, it is therefore easy to perceive how they may be introduced into the augite by water. The carbonate of lime in the altered augite may have the same origin, or it may proceed from the

* Suckow.—Erz. und Gesteinslager im Schwed. Urgebirge, 1831, p. 50.

† Annal. des Mines, xiii.

‡ Phil. Mag. xi. 36.

§ Verhandlungen des Naturhistorischen Vereins der preuss. Rheinlande.

|| English edition, chap. xxxv. Blum—Die Pseudomorphosen, p. 207, und Westphalens, Jahrg. vi, 27.

¶ Rammeisberg—Poggendorff's Annalen xlix, 393.

silicate of lime in the augite by decomposition. Blum found that most specimens of altered augite exhibit copious effervescence with acids, and that they contain more or less carbonate of lime. The three specimens of green earth analyzed by Klaproth,* as well as the green granules analyzed by Berthier and by Von der Marck, likewise contained alkalies. They are not found in some other specimens.

These green granules are very frequently abundant in the chalk and tertiary strata, and are, therefore, of considerable geological importance. They are found in the calcareous, sandy and argillaceous strata† of the chalk series in the south-west of England, in the neighbourhood of Valenciennes, in the district of Aix; at the south border of the extensive level of Münster in Westphalia, and in the Halberstadt and Blandenbergl districts.‡ In the tertiary strata they are not so general as in the chalk strata. The green sand is very conspicuous in the strata overlying the chalk in England. At Woolwich and the Isle of Wight it is found immediately above the chalk, and indeed the flints from the chalk are coated with green sand.

The preservation of these green granules in sedimentary strata shows how little they are liable to undergo alteration.§ This would seem to depend upon their not containing silicate of lime; for it is only in the green earth of Lossasna that lime is found, and in that it amounts to only 2·5 per cent. The presence of magnesia, which amounts to as much as 14 per cent. in green earth, does not favour decomposition, consistently with the general rule that silicate of magnesia is not readily decomposed by carbonated water, while the silicate of lime is very readily decomposed.

With regard to the composition of the silicates of proto- and per-oxides of iron, nothing very definite can be said. In the older analyses, no attention was paid to the relative proportion of the two oxides. Moreover, these silicates always contain other silicates of alumina, lime, magnesia, and alkalies, in varying amount; for which reason the relative proportion between the silica and the oxides of iron cannot be determined: it would appear, however,

* Beitrage, etc., iv, 239.

† In sinking to a depth of 1,068 feet for an Artesian well in Calais, after boring through 718 feet of chalk, a chalk stratum was found, 2·7 feet thick, containing green granules; still lower, clay, at first containing mica and then green granules. The latter were also found in a sandstone underlying the clay.—Comptes rendus, 1847, xxiv, 323.

‡ De la Beche—Geology. German translation by v. Dechen, p. 291, et seq.

§ Ante, p. 65.

to vary very much. Rammelsberg estimated the quantity of both oxides in two specimens of hisingerite.* Approximatively he found the oxygen quotient = 1, when the oxygen of the two oxides is taken as a whole. In another specimen Hermann found it = 0.753.

There is a powerful affinity between silica and protoxide of iron. This may be observed when anhydrous silicates, containing this substance, among others furnace slags, are acted upon by hydrochloric acid. The silica that is separated retains some of the protoxide of iron with great tenacity, and is, on this account more or less green-colored. Even by digesting for several days with concentrated hydrochloric acid, the protoxide of iron can scarcely be separated from the silica. It is only by the action of nitric acid, which forms peroxide of iron, that perfect separation can be effected.† The hydrated protosilicates of iron, such as hisingerite, are decomposed much more readily by hydrochloric acid.

It is very probable that alkaline silicates convert the bicarbonate of iron, in water, into protosilicate of iron.‡ Its formation, therefore, in spaces from which air is excluded, may be easily understood, and the more so since the green earth so frequently contains alkaline silicates, which may be the undecomposed residue of such a reaction.

The above-mentioned phenomena indicate the gradual conversion of protosilicate of iron into persilicate. But it is also evident from the almost unaltered colour of green earth and glaukonite, that this oxidation takes place only under special conditions. Hisingerite is sometimes covered with iron ochre.

It has been shown§ that hydrated peroxide of iron decomposes the silicates of the alkalis, of alumina and lime with formation of persilicate of iron. It is, therefore, possible that these silicates have furnished the material for the formation of persilicates of iron. The nontronite from an iron mine in the Harz has a fine green colour, and according to the careful examination of Biewerd|| does not contain any protoxide of iron, but is a pure hydrated persilicate of iron. It is probable, therefore, that other green-colored minerals of this kind contain either peroxide of iron alone, or both oxides, like pinguite, which according to the analysis by Kersten, contains 29.5 per cent. peroxide of iron, and 6.1 per cent. protoxide.

* Handwörterbuch, 4^{tes} supplement, p. 100.

† Kersten—Schweigger's Journ. lxvi, 15.

‡ Ante, p. 70, No. 47.

§ Ante, p. 71 and 77, Nos. 48, 49, and 50.

|| Journ. für prakt. Chemie, ii, 162.

If these green minerals have been formed in this way by the reaction of hydrated peroxide of iron and the silicates above-mentioned, it is possible that during the alteration the peroxide of iron may have been reduced to the state of protoxide owing to the presence of organic substance, or silicates of both oxides might have been formed at the same time, when the decomposition of those silicates had commenced before the whole of the bicarbonate of iron in the water had been converted into hydrated peroxide of iron.

F.—*Simple hydrated silicates of protoxide of manganese.*

Formation and occurrence.—The hydrated protosilicates of manganese appear to be derived from augite containing protoxide of manganese, in the same manner that green earth and similar protosilicates of iron are formed from augite. The bisilicate of manganese and bustamite are, according to Berzelius and Dumas, anhydrous double silicates of protoxide of manganese and lime, and are apparently not acted upon by acids. A mineral from Franklin, New Jersey, contains, according to Thomson, no lime, but 2·7 per cent. of water. It is identical with the tephroite analyzed by Rammelsberg,* which contains only traces of lime and magnesia.

The presence of carbonic acid to the extent of 7·5 per cent. in the specimens of bisilicate of manganese from the lower Hartz, analyzed by Du Menil† and Brandes,‡ shows that this substance is decomposed by water, containing carbonic acid. Acids have but little action on these minerals. Rammelsberg§ considers horn-manganese, allagite, photicite, rhodonite, hydrosite as compounds of a protosilicate of manganese, with either quartz or protoxide and carbonate of manganese. It is not improbable that these minerals have originated from augite; the lime and protoxide of iron having been partially removed by water containing carbonic acid. The photicite analyzed by Simpson|| was found to contain lime, magnesia and protoxide of iron,—from 14 to 15 per cent. of each—probably the remains of the original mineral, for the quantity of water present, 8·9 per cent., shows that considerable decomposition had taken place. The presence of varying quantities of water and carbonic acid in these minerals, and the absence of these substances in some others show that the agents which

* Poggendorff's Annalen, lxii, 166.

† Gilbert's Annalen, lxi, 194.

‡ Schweigger's Journal, xxvi, 121.

§ Poggendorff's Annalen, lxii, 145.

|| Ibid. lxii, 147.

effect the decomposition have been taken up only in the course of time.*

The black bisilicate of manganese from Klapperud in Dalecarlia agrees with tephroite in its composition after deducting the water which amounts to 13 per cent. according to Klaproth. It is probably altered tephroite, for this mineral readily becomes covered with a black incrustation. Fowlerite, the augitic mineral of Franklin, which agrees very closely with tephroite in external characters, contains, according to Thompson, 3·2 per cent. of water. It contains 13 per cent. of protoxide of iron which is so much more than tephroite contains that it is probable that it has not been formed from this latter mineral, but from augite. The troostite which occurs at Sparta and Sterling in New Jersey, has a composition very similar to that of fowlerite. It contains 7·3 per cent. of water and carbonic acid, and doubtless has the same origin as the last named mineral.

So far as the circumstances under which the hydrated protosilicates of manganese occur, are known, they appear in all cases to have been formed at the place where they are found, from augite containing protoxide of manganese. In the drusy cavities of the amygdaloid at Oberstein, in which the siliceous minerals predominate, there are not unfrequently found upon the amethysts, brown soft masses consisting for the most part of peroxide of manganese. In this instance, therefore, there is no want of silica or of manganese; but, so far as I am aware, no protosilicate of manganese has hitherto been found in these cavities, although green earth occurs very frequently. Hence it still remains undetermined whether protosilicates of manganese have been deposited from water.

The consideration of the silicates of copper, bismuth, zinc, etc., will be reserved for the chapter relating to metalliferous veins.

G. *Compounds of silicates with carbonates, sulphates and chlorides.*

A compound of silicate of soda and a carbonate may be prepared artificially. When the precipitate obtained by adding silicate of soda to an aqueous solution of bicarbonate of lime,† is well washed and mixed with hydrochloric acid, it dissolves with effervescence and without separation of silica. When, however, the lime is precipitated by oxalate of ammonia, the filtrate evaporated to dryness, and the ammoniacal salt driven off by heat, there remains a residue which dissolves partly in water; silica remains and the

* The protosilicates of manganese will be further considered in chap. xxxv.

† English edition, i, 12, No. 11.

solution contains chloride of sodium. Therefore the precipitate formed in the first instance contains carbonate of lime, silica and soda. The two latter substances, however, could have existed only in the state of silicate of soda; and, as this silicate was not separated by washing, it is very probable that it was chemically combined with the carbonate of lime.

Similar compounds occur as minerals. According to G. Rose,* the canoxinite from the Miasgit in the Ural, consists of silicates of soda and alumina and carbonate of lime. According to Whitney,† three varieties of canoxinite which occur in the granite at Litchfield (Maine), consist of silicates of soda and alumina with carbonates of soda and lime. It is not improbable that a compound containing silicate of alumina might be obtained artificially, if this substance were added to the solution of silicate of soda, but this would be difficult on account of the sparing solubility of silicate of alumina. The davyn from drusy cavities in the lava of Vesuvius and the stroganowite from detritus of a river in Dauria are minerals of the same kind. We are not in possession of any satisfactory analysis of the former, but the presence of carbonate of lime cannot be doubted. Stroganowite is, according to Hermann,‡ a variety of canoxinite in which lime predominates.§

Silicates likewise occur combined with sulphates and with chlorides. Thus sodalite contains chloride of sodium; nosean and hauyn, sulphate of soda and sulphate of lime. These minerals may be regarded as compounds of elæolite—silicate of soda and alumina—with the salts mentioned.|| Yttnerite contains a chloride and a sulphate.

* Reise, Nach. dem Ural., ii, 57.¹

† Poggendorff's Annalen, lxx, 443.

‡ Journ. für Prakt. Chemie., xxxiv, 177.

§ Since carbonate of lime precipitates silicates from solution in hydrochloric acid, it may be conjectured that the same precipitation would take place if the silicates were merely dissolved in water. When, therefore, silicate of soda and alumina dissolved in water comes in contact with carbonate of lime, it is possible, even when carbonic acid is not present, compounds of this double silicate with carbonate of lime may be formed.

|| Whitney, loc. cit.

CHAPTER XXVII.

ZEOLITES.

THE occurrence and formation of zeolites will be treated of in the following volume in the chapter on drusy cavities. The substances that are extracted by acids from many rocks, basalt, phonolite, amygdaloid, etc., have been called zeolitic. Since the minerals called zeolites are always hydrated compound silicates, those rocks only can be supposed to contain zeolitic admixtures which contain chemically combined water. Augitic lava is anhydrous, but acids extract a considerable quantity of substance from it and it would be contradictory to call this portion of the rock zeolitic. Basalt contains more or less water chemically combined, and acids likewise extract from it a considerable portion which might be regarded as a zeolitic admixture. But the small quantity of water which this rock contains rarely corresponds with the considerable quantity of substance that may be extracted by acids, and from the great similarity of basalt and lava, it is probable that the former would equally contain substances that may be extracted by acids; so that in the case of basalt and similar rocks, only a portion of this extracted substance can be regarded as zeolitic.

The confusion of zeolitic substance, with such portions of rocks as may be extracted by acids, has led to fruitless attempts to deduce from the results obtained by the analysis of the portion of rocks that may be extracted by acids, evidence for the presence of some particular zeolite in the rock examined.

The presence of zeolitic substances in rocks, in whose drusy cavities and fissures zeolites are found, cannot be questioned. In analcime-dolerite, the analcime is disseminated throughout the entire mass, and occurs in the drusy cavities as fine crystals. There is no doubt that the material for the formation of these crystals has been derived from the rock by water, and other zeolites in drusy cavities may have originated in the same manner. If zeolites were primitive formations, they would always be found in rocks associated with other primitive minerals, such as labrador and augite. It is frequently stated that zeolites occur in rocks, although, by closer examination, it would perhaps appear that they

merely fill up small pores and interstices in these rocks. Breithaupt* says, that zeolites have never been found imbedded in a porphyritic manner in unaltered rocks.

The most frequently observed occurrence of zeolites in drusy cavities and fissures, with quartz and calc-spar which are undoubtedly products of the decomposition of the adjoining rock, furnishes decisive evidence of similarity in the origin of these minerals. But since these products of decomposition would not be removed by water to the same extent that they are formed, they accumulate in the mass of the rock. In melaphyr † we find quartz mineralogically recognizable; the effervescence with acid indicates the presence of carbonate of lime, and from the presence of chemically combined water together with the extraction of a portion of the mass by acids, we may infer the presence of zeolitic admixture. Therefore the substance that is found in the drusy cavities exists likewise throughout the entire mass of the rock though not in crystals. This leads to the inference that the formation of definite zeolitic minerals can take place only when the hydrated silicates have been dissolved by water and conveyed into the empty spaces.

Since analcime and natrolite are the only zeolites which do not contain silicate of lime, they are the only two that can have been deposited from water containing carbonic acid; the formation of the other zeolites presupposes that the water was either free from carbonic acid or contained only enough to effect the decomposition of a portion of the dissolved silicate of lime. If silica and carbonate of lime were present together in solution, the formation of zeolites and of calc-spar might have taken place simultaneously, and this is consistent with the frequent alternation of both minerals in drusy cavities. ‡

Zeolites are decomposed by acids; however silica does not separate from all of them in the gelatinous state; but sometimes in the state of powder as in the cases of stilbite, and epistilbite. Zeolites which present the latter character are decomposed less readily than the others.

I shall adopt an arrangement of the zeolites according to their

* Paragenesis, p 108.

† English edition, iii. Melaphyr.

‡ According to C. List, water that had been boiled with a large quantity of Taunus slate was found to contain silicate of lime, alumina, and some protoxide of iron, together with alkalies. Water would, under ordinary circumstances, extract the same substances although in smaller quantity. The solution of silicate of lime, etc., from amygdaloid rocks, which are so rich in this substance, would take place much more readily.

constituents, at the same time limiting myself to the consideration of those zeolites which are of frequent and general occurrence. Those only of the rarer zeolites will be mentioned of which the processes of alteration are known. The numbers with the letter Q are the oxygen quotients of the minerals after deducting the water, and those with W represent the per centage of water.

First Class.—Aluminous zeolites. These consist of silicates of:—

A. Alumina Soda	Analcime.	Natrolite.				
	Q 0.75 W 8.01	0.67 9.32				
B. Alumina Lime	Laumontite.	Leonhardite.	Stilbite.*	Houlandite.	Scolecite.*	Prehnite.
	Q 0.50 W 15.00	0.45 13.54	0.44? 17.00	0.33 14.33	0.67 13.54	0.83 4.30
C. Alumina Soda Lime	Mesolite.	Mesotype.	Chabasite.	Epistilbite.	Thomsonite.	
	Q 0.67 W 12.17 or 13.45		0.50 22.00	0.44 14.48	1.00 13.66	
D. Alumina Potash Lime	Lime-harmotome.					
	Q 0.50 W 17.00					
E. Alumina Potash Baryta	Baryta-harmotome.					
	Q 0.50 W 15.00					

Most of the zeolites under C contain, besides soda, minute quantities of potash, and most of those under D contain, besides potash, minute quantities of soda.

Second class.—Zeolites without alumina. These consist of silicates of:—

F. Potash Lime	Apophyllite.	
	Q 1.00 W 16.35	
G. Lime combined with silica and boracic acid.	Datolite.	

To these may be added some of the rarer zeolitic minerals, containing substances that are either not present in the others, or present only in small quantity. Thus, kirwanite contains 23.91 per cent. of protoxide of iron, zeuxite 26.01 per cent. of the same

* Calcareous mesotype.

substance; carpholite, 18·3 to 19·2 per cent., oxide of manganese; neurolite 1·5 per cent. magnesia; and onkosine, 3·82 per cent. of the same substance. It may be that zeolites containing protoxides of iron or manganese have not unfrequently been formed in drusy cavities, and have subsequently been decomposed by oxidation; at least the cavities of amygdaloid, containing chalcedony—almost always contain more or less hydrated peroxide of iron, either coating the crystals of quartz and amethyst, or deposited between them. I once found a considerable quantity of peroxide of manganese in such a cavity.*

With the exception of the two rare zeolites just mentioned, the zeolites do not contain silicate of magnesia, although this silicate exists in amygdaloid rocks, sometimes in greater quantity than silicate of lime. But the crusts, similar to ripidolite, which so frequently occur round the cavities in the amygdaloid rocks,† and likewise the presence of steatite in drusy cavities,‡ show that silicate of magnesia is extracted from amygdaloid rocks.

It appears, therefore, that the silicates in drusy cavities are the same as those in the surrounding rock. The kind of zeolite which is formed in these cavities, depends upon the nature of the process of alteration that takes place. In some of these zeolites there are substances, which, like baryta and boracic acid, have not yet been detected in the surrounding rocks.

When it is remembered that the cavities containing chalcedony rarely contain zeolites, or only quantities that are minute compared with the siliceous substances, it is evident that in these rocks the decomposition of silicates predominates over the solution of unaltered silicates. When siliceous substances occur in the drusy cavities of rocks, as in the amygdaloid at Oberstein, these rocks are found to have lost much of their silica.

When the drusy cavities are filled with calc-spar only,§ the decomposition of the silicate of lime must have preponderated in the surrounding rock, perhaps to the exclusion of any other process of alteration. In this case, which is very frequent, the silica of the decomposed silicate of lime must either have remained in the rock, or have been dissolved only to such small extent by water, that it could not be deposited again in the drusy cavities, but was carried away by the water from which carbonate of

* English edition, iii, Drusy cavities.

+ Ibid.

‡ Ibid. ii, chap. xli.

§ Ibid. iii, drusy cavities.

lime had been deposited. In either case the proportion of silica in the rock was increased.

No one will doubt that in rocks which are identical with amygdaloid rocks, but which have no cavities, the same processes of alteration would take place. The substances extracted by water from the latter would not be deposited, but the rock would experience the same alteration by the percolating water as the amygdaloid rock. The more frequent occurrence of soda than of potash in zeolites is owing partly to the fact that amygdaloid rocks are richer in silicates containing soda than in potash silicates, and partly to the more easy extraction of silicate of soda by water.

The comparison of the oxygen quotients of zeolites with those of felspar,* shows that they are the same. However, felspar has not been found in the drusy cavities of amygdaloid rocks. Jenzsch has recently discovered in the drusy cavities of a rock, called by him amygdaloid-ophyr, a mineral, weissigite, which, according to his analysis, has exactly the composition of orthoclase, and contains a minute quantity of lithia. However this rock has the composition of trachyte,† and the occurrence of felspar in the drusy cavities of rocks having this composition, and even in sedimentary rock, is by no means uncommon, as will be seen in the following chapters. Moreover, the conversion of analcime and laumontite into felspar shows that the formation of the latter may take place indirectly in the drusy cavities of amygdaloid rocks.

Felspar with the form of Analcime.—Haidinger‡ found a dark flesh-coloured mass with the form of analcime at the Calton Hill, near Edinburgh. The crystals were sometimes quite hollow, sometimes they contained calc-spar, or a brown earthy substance. Breithaupt informs me that he has found ordinary felspar with the form of analcime, in amygdaloid rock near Dillenburg.

The following diagram shows how analcime may be converted into orthoclase:—

	Silica.	Alumina.	Soda.	Potash.	Water.
Analcime	8 eqts.	3 eqts.	3 eqts.		6 eqts.
Silicate of potash	+ 4 „		— 3 „	3 eqts.	— 6 „
Orthoclase	12	3 .		3 .	

* English edition, chap. xxviii.

† Ibid. iii, Trachyte.

‡ Sitzungsberichte der Akademie der Wissenschaften zu Wien, iii.

If, therefore, analcime takes up silicate of potash of the above composition, it might be converted into orthoclase; and since silicate of soda is decomposed by carbonate of potash,* water containing carbonate of potash and silica, may effect the conversion of analcime into orthoclase.† These substances are certainly present in water percolating through amygdaloid rocks. The zeolites in the drusy cavities are the latest deposits from this water,‡ and, therefore, the conversion of laumontite and analcime into orthoclase is a later change. Now, since the decomposition of the silicate of potash in rocks takes place subsequently to the decomposition of the silicate of soda, the presence of carbonate of potash, arising from this decomposition, is chiefly to be conjectured in the water which has penetrated the drusy cavities after the formation of the most recent deposits in them. The silicate of potash, which is dissolved unaltered, may, in an equal degree with carbonate of potash, be conjectured to have been present in water which has last penetrated the drusy cavities. The latter as well as the former may, when carbonic acid was present, have effected the conversion of laumontite into orthoclase.

When, as in the present instance, the succession of the processes of alteration in rocks corresponds with that of the deposits and their alteration in drusy cavities, it is a sure sign that the true mode of accounting for the phenomena has been found. The formation of analcime in drusy cavities presupposes the presence of silicate of soda in the water; its conversion into orthoclase requires the presence of silicate of potash in the water penetrating subsequently, and this corresponds with the succession in which alkaline silicates are extracted from rocks.

Analcime occurs in the mass of the dolerite of the Cyclopean Islands near Catania in Sicily, and constitutes at least two-thirds of them, as this dolerite forms the basis of the largest of these islands so far as it is visible,§ and, therefore, the conversion of this zeolite into orthoclase has a geological importance. There is

* English edition, ii, 65, No. 38.

† Since there is scarcely any specimen of orthoclase that does not contain at least traces of soda, the whole of the soda would not be removed from analcime. Awdejew found in analcime, from the zircon-syenite, near Brevig, only a trace of potash. I found a scarcely recognizable trace in analcime, somewhat decomposed, from the Seisser Alps; no other analyses indicate the presence of potash. It is, therefore, remarkable, that Sartorius von Waltershausen—über die vulcanischen Gesteine, p. 266—should have found, in pure analcime crystals from the Cyclopean Islands, 4.46 per cent. potash, besides 7.92 per cent. soda. If such analcime containing potash occurs frequently, it would be still more liable to conversion into felspar.

‡ English edition, iii, Drusy cavities.

§ C. Gemmellaro.—Die Basalt-Gebilde, von Leonhard, i. 228.

a possibility that such a mass of dolerite might, so far as its silicate of potash admits, be converted into a felspathic rock, although such a metamorphosis has not as yet been observed.

Prehnite with the form of analcime. This pseudomorph has been observed by Haidinger, Blum, Grandjean, F. Sandberger, in various rocks*—trapp from Dumbarton, diorite? diabase and amygdaloid rock. From the description given of some specimens of this pseudomorph, the alteration would seem to have commenced at several points in the interior of the crystals. This pseudomorph is very important because it indicates the introduction of lime. Pseudomorphous prehnite that was analyzed by G. Leonhard,† contained only 19 or 22·6 per cent. lime, while in ordinary prehnite it amounts to 27 per cent. The alteration would appear, therefore, to have been incomplete.‡ Riegel found in the analcime of Niederkirchen, 6·5 per cent. soda, and 5·7 per cent. lime.§ Jackson found in the analcime of Kewenaw point, Lake Superior, 8·52 per cent. soda, and 3 per cent. lime. It may, therefore, be conjectured, that these specimens of analcime were already in the first stages of conversion into prehnite.

Since silicate of soda is decomposed by sulphate of lime, and by chloride of calcium,|| water, containing these salts, coming in contact with analcime, might convert its silicate of soda into silicate of lime, while the soda would be removed as sulphate. The displacement of soda by lime in natrolite, must be supposed to take place in the same manner.

When finely powdered analcime was digested for twenty-four hours with solution of sulphate of lime at a moderate temperature, the lime separated from the clear solution by oxalate of ammonia, the filtrate evaporated to dryness, and ammoniacal salts separated from the residue by heat, there remained a residue which dissolved in water; the solution became turbid with acetate of lead, and after filtering and separating excess of lead by sulphuretted hydrogen, the filtrate gave by evaporation to dryness, a residue that had a distinct alkaline reaction. It consisted, therefore, of carbonate of soda, and this shows that the silicate of soda in analcime was partially converted into sulphate of soda by the action of sulphate of lime.

* Blum. Die Pseudomorphosen, p. 100, et seq., und 2^{ter}. Nachtrag, p. 45.

+ On some pseudomorphous zeolitic substances from Rhenish Bavaria, 1841, p. 43, et seq.

‡ The considerable amount of alumina obtained in this analysis, and the method adopted afforded ground for suspicion of inaccuracy.

§ Jahrbuch der praktischen Pharmacie, xiii. 1.

|| English edition, i. 11.

The favorable result of this experiment induced me to repeat it with a larger quantity of solution of sulphate of lime.* Analcime was digested for several hours, with 1·18 sulphate of lime dissolved in 598 parts water at a moderate temperature; the solution from which lime had been separated by means of oxalate of ammonia contained 0·009 sulphate of soda. Assuming that the same quantity of silicate of soda would be decomposed in each successive repetition of this experiment, the silicate of soda would be completely converted into silicate of lime by 36 repetitions.

I should have tried the effect of chloride of calcium upon analcime in the same manner, but the chloride of calcium contained traces of alkalies, and this was also the case with chloride prepared from marble and from chalk, although the chalk was washed, and the marble was previously dissolved in hydrochloric acid, the lime precipitated as carbonate, carefully washed and then dissolved by hydrochloric acid.

As the pseudomorphs described by Blum were surrounded by datolite that was very much decomposed, he conjectures that the lime introduced into the analcime may have been derived from this zeolite. The decomposition of borate of lime by means of silicate of soda,† favours this opinion.

Talc, with the form of analcime, is stated by Weibye‡ to occur in cavities in syenite near Röra, in Norway. Analysis must determine whether the analcime has really been converted into talc.

Decomposed Analcime.

	I.	II.	III.	IV.	V.
Silica	57·34	55·67	52·59	55·98	55·03
Alumina	22·58	22·47	21·55§	22·94	22·96
Soda	11·86	12·33	11·53	12·27	13·97
Carbonate of lime	0·35	...	3·10	...	...
” magnesia ....	...	0·44	0·80	...	...
Water	9·60	8·79	8·28	8·81	8·04
	101·73	99·70	97·85||	100·00	100·00

* In order to avoid error, a portion of the sulphate of lime was tested for alkali in the same manner. Traces of an alkaline salt were found, but it was however perfectly removed by prolonged washing of the sulphate of lime.
+ English edition, ii, 81, No. 56.
‡ Archiv. für Mineral., etc., xxii, 537.
§ Somewhat ferruginous.
|| The reason of this deficiency could not be ascertained, on account of the want of material.

I. Analcime from Blagodat in the Tyrol by Henry.*

II. Somewhat decomposed analcime from the Seiner Alps, analyzed by myself. Another specimen contained 55.51 per cent. silica, and did not effervesce with acids.

III. Analcime, very much decomposed, from the same place, analyzed by myself. It effervesced copiously with acids; after moderate ignition, it effervesced somewhat less, and had, therefore, lost some carbonic acid, so that the per centage of water is rather less than 8.25. The carbonic acid was not determined directly but by calculation from the quantities of lime and magnesia. The large loss of 2.15 per cent. is undoubtedly owing to the presence of organic substance, for the alkaline chlorides obtained were quite black. As this analcime, when unaltered, does not, according to H. Rose, contain either lime or magnesia, it cannot be supposed that the carbonates are products of decomposition. If they are supposed to be accidental, the composition of the mineral would be that under IV.

IV. Calculated composition of the above specimen of analcime. As the analyses of unaltered analcime correspond very closely, this may be regarded as the normal composition.

Comparing III and IV with V, it will be seen that the alteration is accompanied by loss of soda and introduction of water. The analcime I was probably in the same state of alteration as it had a fatty lustre.

Blum informs me that he has observed in a crystal of analcime from the Tyrol, an aperture of more than half an inch, through which he could detect a crystalline mixture of carbonate of lime in the interior. The unaltered crust of the crystal was only half a line thick. It is questionable whether this carbonate of lime originated from a considerable quantity of lime in this specimen of analcime, or whether the interior substance of the crystal was displaced by means of bicarbonate of lime. A fuller explanation of this phenomenon is much to be desired.

Natrolite, or soda-mesotype, with the form of elæolite.—This alteration has already been spoken of.† The following analyses by Scheerer‡ enable us to recognize the essential features of this change, as they refer to specimens of elæolite and of zeolites from the same locality.

* Poggendorff's Annalen, xlv, 264.

† English edition, ii, 114.

‡ Poggendorff's Annalen, xlv, 293, et seq. ; xlix, 359, et seq., and lxx, 278.

	I.	II.	III.	IV.	V.	VI.
Silica	44.45	45.23	45.55	47.97	48.12	47.86
Alumina	31.92	32.66	32.00	26.66	26.96	26.62
Peroxide of iron	1.10	0.56	1.41	0.73	0.22	...
Lime	0.28	0.34	Spur	0.68	0.69	...
Soda	15.71	15.71	16.09	14.07	14.23	16.20
Potash	5.17	5.67	5.02	Spur	Spur	...
Water	2.07	0.61	0.78	9.77	10.48	9.32
	100.70	100.78	100.85	99.88	100.70	100.00

I. Elæolite of a dirty brown colour from the neighbourhood of Brevig. Mean of three analyses.

II. Green elæolite from Fredrikswarn in Norway. Mean of two closely corresponding analyses.

III. Brownish elæolite from the same locality.

IV. Flesh colored wernerite.

V. White variety of the same mineral. Both are frequent in the zirkon-syenite. They differ only in the presence of a small quantity of amorphous peroxide of iron in the colored variety. According to Blum,* these minerals are pseudomorphs after clæolite.

VI. Theoretical composition of natrolite.

It will be seen that in this alteration of I, II, or III, alumina and peroxide of iron have been partially removed, while almost the whole of the potash has been removed and water introduced in its place. An approximative calculation shows that a portion of the soda has likewise been removed, and that in this way the relative proportion of silica has been increased. The increase of lime is probably owing to the action of water which has effected the alteration and deposited carbonate of lime. This pseudomorphic process is very interesting, because it shows in opposition to all previous observation that potash is separated, while soda remains, or at most, is removed only in small quantity.

The conversion of elæolite into natrolite appears to be frequent. The very variable quantity of water in elæolite, amounting in I to 2.07 per cent., the small quantity of alumina in I, compared with that in II and III, and the small quantity of potash, compared with that in II, indicate that the conversion into zeolitic substance, has already commenced. This is the more evident

* Zweiter Nachtrag zu den Pseudomorphosen, p. 132.

from the comparison of II, with Gmelin's* analysis of the green elæolite from Laurvig, for in this the alumina amounts to two per cent. more than in II, and the water amounts only to 0·6 per cent. Therefore, the elæolite analyzed by this chemist was less decomposed than II.

Since silicate of potash and chloride of sodium are mutually decomposed,† and since the latter substance is almost always present in water, it is possible that in the previous instance it was not silicate of potash, but the silicate of soda produced by this reaction that was removed. The simultaneous separation of an alkali and of alumina justifies the conjecture that they were removed in combination,‡ more especially as in the conversion of elæolite into natrolite, a part of the silicate of alumina, and almost the whole of the silicate of potash are decomposed, and the silica left, so that the alumina and potash cannot be removed as silicates. Moreover, the ready solubility of the aluminate of potash adds further probability to this conjecture. If this view is correct the soda which is separated would likewise be separated in the state of aluminate of soda, and probably the potash would be combined with the alumina in greater amount than the soda, only because it is the stronger base.

These conjectures are based upon the proved extraction of alumina from silicate of alumina, by means of alkaline silicates,§ and upon the inference derived from this fact, that this substance may be extracted from minerals containing silicates of alumina and of alkalies, by the action of water.

Prehnite with the form of natrolite.—Haidinger and Blum describe this pseudomorph.¶ The crystals are large and consist almost entirely of prehnite partly in long columnar crystals, and partly in reniform masses. In this alteration soda is displaced by lime and a part of the water is separated.

Decomposition of natrolite.—Gehlen and Fuchs¶ analyzed a

* Schweigger's Journ. xxxvi, 84.

† English edition, i, 12.

‡ Potash combines with alumina in definite proportion; 47·87 of the former with 51·13 of the latter—Unverdorben, in Poggendorf's Annalen, vii, 323—and this compound may be crystallized—Fremy—Comptes rendus, xv, 1106.—In the conversion of elæolite into natrolite, the potash and alumina are separated in very nearly the same proportion. If water removed such a compound of alumina with potash, it would soon be decomposed by means of carbonic acid, leaving hydrated alumina; and it is probable that diasporé, gibbsite, &c., have originated in this manner.

§ Ante, p. 65, No. 39.

¶ Erster Nachtrag, p. 60.

¶ Schweigger's Journal, viii, 361.

decomposed mineral substance which enveloped a crystal of natrolite that was disintegrated at the surfaces. The silica had been reduced to one-sixth, only a minute quantity of alumina remained, while on the other hand the lime had been considerably increased in quantity and was mostly in the state of carbonate. If this substance is decomposed natrolite, the alteration would have consisted in the separation of silicate of alumina, and the conversion of silicate of lime into carbonate. The removal of the former substance and the retention of the latter is very remarkable, and requires to be further investigated.

Laumontite.—This mineral undergoes alteration by exposure to the air and becomes opaque. Malaguti and Durocher* found that within a month it lost, in the vacuum of an air pump, 2·26 per cent. and, in air dried by sulphuric acid, 3·85 per cent.; but after this the decrease of weight was very small. The mineral does not effloresce in moist air, and that which has been dried takes up water again from moist air or when dipped into water. Laumontite when heated loses water, between 50° and 212° F., 3·17 per cent.; between 212° and 329° F. 2·91 per cent.; between 392° and 572° F. 1·20 per cent. From the occurrence of laumontite in drusy cavities and in fissures, it follows therefore, that these spaces must have been filled with moist air, both during and after the formation of this zeolite.

According to Berlin† all the mineral substances called red-zeolite, meal-zeolite, adelforsite, etc., are merely laumontite more or less disintegrated.

Felspar with the form of laumontite.—Haidinger‡ was the first to point out this remarkable alteration. The pseudomorphs occur in cavities in the trap rocks of the Kilpatrick Hills near Dumbarton. The interior of the crystal is tolerably pure pale flesh coloured; but the line between the outer and inner crust of the crystal is often distinctly green, and still shows the point at which the substance of the laumontite was first displaced by the small crystals of felspar. The intermediate portion is either hollow or filled with a dark green substance analogous to steinmark.

This phenomenon so far attracted the attention of G. Rose and myself, that we examined the specimens of laumontite in the Berlin collection of minerals, and at the outset observed similar alterations.§ My son undertook the analysis of some fragments

* Annal. des Mines. Sér. 4, ix, 325.

† Poggendorff's Annalen, lxxviii, 416.

‡ Loc. cit.

§ Jahrbuch für Mineral, &c. 1850, p. 43.

of these pseudomorphs, the result of which is given under I. Under II is the analysis of a specimen of felspar, from a lode near Schemnitz, which will be regarded as originating in the wet way, at least by those geologists who ascribe the same origin to the metalliferous minerals.

	I.	II.	III.	IV.
Silica	62.00	64.00	39.12	56.33
Alumina	20.00	18.00	13.43	19.34
Peroxide of iron	0.64	0.53	2.60	3.73
Lime	0.60	0.78	25.18	11.64
Magnesia	spur	0.31	....	....
Potash	16.54	15.43	....	....
Soda	1.07	0.79	....	....
Oxides of copper and lead ....	...	0.32	....	....
Loss by ignition	0.87	0.54 *	6.22	96
Carbonate of lime ....	...	...	13.54	....
	101.72	100.70	100.00	100.00

Although in I the silica amounts to less, and the alumina to more than in orthoclase, probably owing to the admixture of some remnant of undecomposed laumontite, which would also account for the loss by ignition; still the great preponderance of potash over soda justifies the opinion that the substance of this pseudomorph is really orthoclase. The felspar II, which corresponds very closely with that of Baveno, is decidedly orthoclase.

This alteration may consist in the substitution of silicate of potash, having the following composition, for the water and lime of laumontite:—

	Oxygen of the			
	Silica.	Alumina.	Lime.	Potash.
In laumontite....	8	3	1	
In silicate of potash	+ 4	..	..	+ 3
	..	..	— 1	
In orthoclase	12	3	0	3

The lime would be removed in the state of carbonate, so that the requisite condition of the alteration would be the presence of water containing carbonic acid, and silicate of potash. Since silicate of lime is decomposed by carbonate of potash,† water con-

* Water.

English edition, i, 8.

taining carbonate of potash and silica may effect the conversion of laumontite into orthoclase, after the separation of the chemically combined water.

Therefore, the same substances that effect the conversion of analcime into orthoclase, may also effect the conversion of laumontite into orthoclase.

The conversion of laumontite into felspar appears to be somewhat frequent. Grandjean,* found such pseudomorphs in fissures of a decomposed greenstone near Dillenburg. It is seldom that the laumontite crystals, which appear corroded, are wholly converted into felspar. According to F. Sandberger,† pseudomorphs of this kind an inch long were found near Obersheld, in Nassau, in a drusy cavity. Their physical characters are identical with those of orthoclase. A partially disintegrated specimen of laumontite, from the latter locality, was found by Wildenstein‡ to have the composition III, and after deducting the carbonate of lime the composition IV. Consequently a portion of the lime and of the water has been separated; the former as carbonate, but it does not appear from the analysis whether any trace of potash had been introduced, or whether there had merely been a decomposition by means of carbonic acid.

In twelve analyses of laumontite, the quantity of lime appears to vary from 9 to 14 per cent., generally approximating to 12 per cent., where it is less than this there can be no doubt that decomposition has already commenced.

As laumontite also occurs in granular and earthy masses, it is possible that orthoclase with its own crystal form, may have been formed from this. It may, therefore, be supposed that orthoclase in granite and gneiss has originated from laumontite, for this mineral does occur in those rocks though somewhat rarely.

Prehnite with the form of laumontite.—F. Sandberger§ has frequently observed this pseudomorph. The laumontite is covered with microscopic crystals of prehnite, and is, to a certain depth, entirely altered, the nucleus however consisting of unaltered laumontite. Grandjean|| found laumontite altered in this manner, associated with calc-spar, the crystals being surrounded by a crust of prehnite. In this alteration, some silica and alumina and a considerable amount of water must have been

* Jahrbuch des Vereins für Naturkunde un Herz. Nassau, vii, 219.

† Jahrbuch für Mineral., &c. 1851, p. 156.

‡ Jahrbuch des Vereins für Naturkunde, vi, 134.

§ Jahrbuch für Mineral., &c. 1851, p. 156.

|| Jahrbuch des Vereins für Naturkunde im Nassau, vii, 218.

separated, and lime substituted in their place; the association with calc-spar is remarkable, and further investigation is desirable.

Prehnite with the form of leonhardite.—Discordant opinions were put forward as to the nature of the original mineral which had suffered conversion into prehnite: Blum* however brought forward satisfactory evidence that it was leonhardite. In this alteration some silica, alumina, and water are eliminated, while lime is substituted in their place.

Stilbite.—Among 19 analyses of this mineral there are 15 in which the presence of potash and soda is stated, the quantity rising to as much as 2·2 per cent. These alkalies are either essential constituents, or they have been introduced subsequently and have displaced a portion of the lime. In the latter case a conversion into felspar must be regarded as possible, more especially so since stilbite approximates so closely in point of composition to laumontite.

According to Beudant the disintegration of stilbite appears to be accompanied by a diminution of the silica.

Quartz with the form of stilbite.—One specimen, consisting of an aggregate of quartz, presents the laminar structure of stilbite; in another specimen a number of crystals are covered with a rough crust of quartz, while the interior is either hollow or filled up with quartz.† The remarks made respecting pseudomorphs after heulandite may likewise be applied to these. In one of them, layers of quartz and calc-spar alternate; this is either a product of the decomposition of silicate of lime or has been deposited by water.

Quartz with the form of heulandite.—These pseudomorphs are described by Haidinger and Blum‡ as being more or less hollow, with the interior surfaces quite rugged. It has not yet been determined whether they are alteration or displacement pseudomorphs. As heulandite contains 60 per cent. silica, the quartz may have been formed from it, and the hollow nature of the pseudomorphs favours the opinion that they have been formed by alteration. However, there is some difficulty in accounting for the removal of alumina. Since heulandite has been deposited from water, it might likewise be removed by water while silica was deposited in its place, and if this were the case the pseudomorph would be formed by displacement.

* Die Pseudomorphosen, p. 104 et seq.

† Haidinger and Blum, loc. cit, p. 12.—Sillem.—Zweiter Nachtrag zu den Pseudomorph. p. 10.

‡ Erster Nachtrag zu den Pseudomorph. p. 11.

The drusy cavities of amygdaloid rocks frequently contain very porous masses of quartz, which are considered by Blum to originate from chabasite, stilbite, and laumontite that have undergone decomposition. Chabasite crystals are not unfrequently somewhat disintegrated at the surface, sometimes quite corroded and represented merely by a skeleton of quartz. Further investigation is required to determine whether these masses of quartz are really products of the decomposition of the zeolites.

Prehnite is characterized by being the product of the alteration of four other zeolites—laumontite, leonhardite, natrolite, and analcime. The prehnite from Gabbro, examined by Amelung* contained 1·03 per cent. soda, which may, perhaps, originate from analcime.

Prehnite with the form of calc-spar.—A displacement pseudomorph of this kind was described by Blum† as hollow and formed by incrustation, some prehnite having been deposited subsequently in the interior. The prehnite from an extensive lode near Niederschelt‡ effervesces with acids in some parts; but it has not been shown whether the carbonate of lime indicated by this reaction is the product of decomposition, or whether it was deposited together with the prehnite. The displacement of carbonate of lime by prehnite presents another relation of these two substances.

Mesolite—lime and soda mesotype.—Thomson§ states that the interior, hard, splintery mass of the mesotype at the Giant's Causeway has the composition A, while the outer soft pulverulent portion has the composition B.

				A.	B.
Silica	....	....		48·88	46·00
Alumina	....	....		26·36	27·60
Lime	....	....		7·64	15·20
Soda	....	....		4·20	....
Magnesia	....	....		2·46	....
Water	....	....		12·32	14·35
				101·86	103·15

* Rammelsberg, Zweites Supplement, p. 118.

† Zweiter Nachtrag zu den Pseudomorph., p. 98.

‡ I was much surprised at the great number of prehnite lodes in the greenstone about Dillenburg.

§ Phil. Mag. December, 1840.

The somewhat considerable surplus in these analyses admits of their accuracy being questioned; but it is at least certain, that an alteration progressing from the exterior has taken place, and that soda has been displaced by lime. The substance corresponding to A may be regarded as mesolite; that corresponding to B as skolezite—lime mesotype—the latter being the product of the former by alteration.

Fuchs* observed that the mesolite crystals from the Tyrol are cracked, and in other respects appear as if they had been exposed to considerable pressure.

Chabasite.—Rammelsberg † remarks that lime-chabasite may be distinguished from soda-chabasite—gmelenite—although the latter contains, besides soda, some lime. As the amount of silica in lime-chabasite varies, Berzelius conjectured that the larger proportion might be owing to an admixture of quartz. Rammelsberg ‡ did not find any quartz in the chabasite of Aussig which has the smallest proportion of silica—47·4 to 48·4 per cent.—while carbonate of soda dissolved 47·95 per cent. of the silica obtained in the analysis of chabasite from Nova Scotia and left 8·04 per cent. undissolved. The discrepancies in the analyses appear to be owing to this circumstance, although some of the analyses may refer to partially decomposed chabasite. Suckow § analyzed the underneath bright and solid portion C of a chabasite crystal as well as the exposed and disintegrated portion D which effervesced with acids.

			C.	D.
Silica	....	....	48·40	47·29
Alumina	....	....	19·13	19·16
Lime	....	....	1·88	5·78
Potash	....	....	8·13	1·47
Soda	....	....	1·47	1·50
Carbonic acid	....	....	...	3·20
Water	....	....	21·01	21·00
			100·02	99·40

However remarkable this decomposition may appear, it has an

* Schweigger's Journal, xviii, 17. It would be interesting to examine on the spot whether these crystals occur in fissures or in drusy cavities, and whether the surrounding rock presents indications of shifting or pressure.

† Handwörterbuch, p. 150.

‡ Ibid, p. 149.

§ Die Verwitterung im Mineralreiche, p. 148.

analogue in the decomposition of mesolite. In the latter case soda is displaced by lime, and in the former, the greater part of the potash is displaced by the same base. If this were the case the introduction of carbonic acid must have been the result of subsequent alteration, because carbonate of lime could not have displaced potash. In both cases, as in all others where alkalies are displaced by lime, the alteration can only be attributed to water containing in solution sulphate of lime or chloride of calcium.*

Moreover, there is no single analysis of chabasite which shows such a considerable amount of alkalies in proportion to the lime as C; in all other analyses the lime preponderates considerably over the alkalies. Perhaps the mineral analysed by Suckow was gmelinite, but in this, soda and not potash preponderates over the lime.

Lime-harmotome. The analyses of this zeolite vary very much, owing partly to imperfect separation of other minerals associated with it, and partly to partial decomposition. Traces of baryta have been found in some specimens of lime-harmotome.

Baryta-harmotome. This mineral generally contains minute quantities of lime. One specimen was mixed with 8·8 per cent. carbonate of lime, which was perhaps a product of decomposition. This, however, would presuppose a greater quantity of silicate of lime than is found in any baryta-harmotome.

Apophyllite. This zeolite is characterized by containing fluorine in some instances to the extent of 1·54 per cent., and probably combined with calcium. It has already been stated that this mineral may be dissolved in water, and again obtained in crystals.† My conjecture that cold water would also exert solvent action upon it has been confirmed, for I have found that when powdered it dissolves in 28802 parts of water. This solution is, however, accompanied by a partial decomposition, for the residue obtained by evaporation was deliquescent and alkaline, so that the silicate of potash had been partially converted into carbonate of potash. The residue had the composition I; and after deducting the carbonic acid, the composition II. The apophyllite had the composition III.

* English edition, i, 2, No. 8.

† English edition, i, 60.

	I.	II.	III.
Silica	19.17	19.17	19.17
Carbonate of lime	24.16	13.56	9.45
" potash	20.42	13.92	1.92
Loss by ignition	25.83	25.83	5.93 *
Organic substance †	10.42		
	100.00		

Although the analysis of the residue was imperfect, since it amounted to only 2.4 grains, still it is evident from a comparison of II with III that the bases of the apophyllite were wholly, or for the most part, converted into carbonates by the minute quantity of carbonic acid in the distilled water used, and that the bases, especially potash, were dissolved in much larger proportion than the silica. It may therefore be expected that this zeolite would be entirely decomposed by large quantities of water, and that the bases would be dissolved, together with a portion of the silica. Further action of water would dissolve the residual silica, until finally, nothing would be left.

I am unable to say whether, in Wöhler's experiment ‡ the apophyllite was dissolved without decomposition or not. A repetition of the experiment, and an examination of the water, would be interesting. It is, however, certain that apophyllite may be crystallized from its solution in water, whether that is accompanied by decomposition or not.

Apophyllite loses a portion of its water when exposed to the air, but it has not yet been ascertained whether it loses the whole. It becomes opaque and acquires a mother-of-pearl lustre, the form being more or less retained. Altered apophyllite of this kind effervesces with acids, showing that a portion of the silicate of lime has been converted into carbonate,§ as in the previous experiment.

Meteoric water certainly contains as much carbonic acid as distilled water, and the water in vegetable soil contains much

* Not examined for fluorine.

† The large quantity of organic substance is not remarkable, as it was also found in the analysis of the apophyllite III; and as the quantity of the mineral employed was much greater than the water was able to dissolve, so that the greater portion of the organic substance was extracted from the mineral.

‡ English edition, i, p. 60.

§ Fuchs and Blum.—Pseudomorphosen, p. 22.

more, so that it is evident the minuteness of the quantity of this substance is no obstacle to the decomposition of silicates. Indeed, it could not be supposed that any silicate would be dissolved without decomposition, unless we knew that water is deprived of its carbonic acid by the formation of carbonates near the surface, and thus becomes capable of dissolving silicates without decomposition at lower points.

A specimen of decomposed apophyllite from the Scisser Alps, which did not effervesce with acids, had the following composition, I and II.

	I.	II.	III.	IV.
Silica '	53.32	53.28	55.02	52.43
Alumina and peroxide of iron	1.29	2.23		
Lime	24.42	23.54	24.31	25.86
Potash	not	3.10	3.20	5.36
Soda	estimated	1.75	1.81	
Fluorine ....	...	0.023	0.02	
Loss by ignition	15.15	15.15	15.64	16.35
		99.073	100.00	100.00

The deficiency in I and II represents organic substance ; the chlorides were quite black.

The calculated composition of II, after deducting the alumina and peroxide of iron, is given under III.

The theoretical composition of the mineral is IV.

A comparison of III with IV shows that in the decomposition of this mineral there was a partial separation of lime and water, so that the quantity of silica is relatively increased. Comparing III with previous analyses of apophyllite, it appears that there are none in which the proportion of lime and water is so small, or the proportion of silica so large, as in this. There can be no doubt that the deficiency of lime had been extracted by the action of carbonic acid ; however, the carbonate of lime was removed, while in the specimen of apophyllite analyzed by Fuchs it had been wholly or partially deposited.

In the previous analyses of apophyllite the amount of fluorine varies from 0.24 to 1.54 per cent. In no instance is it so low as in III, and this leads to the conjecture that the greater portion of the fluorine is removed in the decomposition of apophyllite.

It is worthy of remark that such a small loss of lime and

water should be accompanied by such a considerable degree of decomposition, for the specimens I and II were quite opaque and white, and although the form was tolerably well preserved, the edges and corners of the crystals were somewhat rounded.

None of the former analyses of this mineral indicate the presence of soda, and it would appear, therefore, that the decomposition may be accompanied by a partial displacement of potash by soda, and this would be quite possible if the water by which the decomposition was effected contained chloride of sodium, a substance very frequently present in water.*

This induced me to undertake the analysis of the fine transparent apophyllite of Andreasberg, which I found to have the composition I.

	I.	II.	III.
Silica	51.33	51.33	50.20
Alumina and peroxide of iron	1.71	....	....
Lime	25.03	25.86	24.52
Magnesia	trace	....	....
Potash	3.94	4.90	....
Soda ...	0.37	....	....
Fluorine ....	...	1.28	1.09

The water and fluorine could not be estimated owing to deficiency of material.

Rammelsberg's† analyses are given under II and III.

The close correspondence between these three analyses speaks strongly in favour of the unaltered condition of the mineral, and the uniformity in the composition of the Andreasberg apophyllite and renders it probable that II and III likewise contained soda. Accordingly, it may be expected that soda would be found in most, if not in all, specimens of apophyllite.

Chalcedony with the form of datolite.—This pseudomorph from Heytor in Devonshire‡ contains, according to Wöhler§, 98.5 per cent. silica. It may be regarded as an alteration pseudomorph, as borate of lime might have been extracted and removed by water, leaving the silica. If the chalcedony amounts to so much as 38 per cent. of the datolite, it may be merely a product. If it

* English edition, i, 12, No. 9.

† Zweites Supplement, p. 17.

‡ A. Levy, Haidinger, and Blum.—Die Pseudomorphosen, p. 56.

§ Poggendorff's Annalen. xii, 136.

amounts to more than this, either silica has been deposited by water in the place of boracic acid and lime, or the datolite substance itself has been displaced by silica. If the alteration commenced by the conversion of the lime into carbonate, there can be no doubt that the carbonate of lime was subsequently displaced by silica.

I will conclude this chapter with a few general remarks. While in the conversion of elæolite into natrolite, water is introduced, this substance is partially removed in the conversion of natrolite into prehnite. In the conversion of analcime, laumontite, leonhardite, and natrolite into prehnite, and in the conversion of mesolite into skolezite, there is this common character, that lime is introduced. In the case of analcime, natrolite, and mesolite, soda is displaced by lime; in the case of laumontite and leonhardite, a part of the alumina is displaced by lime. In the alteration of analcime, laumontite, leonhardite, and prehnite, a part of the water is separated. The previous pseudomorphs are very remarkable because they are among the few in which lime is the displacing substance, while on the contrary all minerals containing silicate of lime lose lime either wholly or partially when exposed to the influence of conditions which produce decomposition or alteration. These opposite processes show in a striking manner the remarkable play of chemical affinity that obtains in the formation and alteration of minerals.

Bunsen* describes an experiment which he considers sufficient to solve the problem of the origin of hydrated silicates in plutonic rocks. For my remarks on this subject I must refer to the German edition.†

* Poggendorff's *Annalen* lxxxiii, 236.

† German edition. ii, 2150 et seq.

CHAPTER XXVIII.

FELSPAR.

AMONG the most frequent varieties of felspar, the largest proportion of silica is 69·09 per cent. as in albite, but in the rare mineral, petalite, it amounts to 79·12 per cent. The smallest proportion of silica is 44·10 per cent. as in anorthite.

The analyses of felspar show that all kinds contain potash and soda,* but that the proportions are very variable. The maximum proportion of potash is found in leucite and orthoclase; the maximum of soda in albite, labrador, and ryakolite.

It may be assumed as a general rule that felspar is more easily decomposed into kaolin and analogous substances, the greater the proportions of soda and lime. Where albite and orthoclase are associated, the former is always decomposed first.†

Unaltered felspar does not contain any water, and in the altered mineral the quantity of water is always proportionate to the degree of alteration. The increase in the quantity of water is likewise accompanied by a quantitative alteration of the constituents.

A.—ORTHOCLASE, COMMON FELSPAR, ADULAR, &C.

This mineral in its normal state is not acted upon by acids either before or after ignition.

Occurrence.—Orthoclase is the most frequent and abundant of the feldspathic minerals. It occurs in granite, gneiss, granulite, syenite, felspar-porphry, &c.; partly in crystals, partly as the predominating mass, and sometimes in veins or druses. In sedimentary slate rocks, especially clay-slate and grauwacke, it forms an essential constituent, and sometimes occurs crystallized in these rocks. In the third volume the felspar occurring in these rocks and in sandstone &c., will be more specially treated of, and it will there be shown that all the felspar in sedimentary rocks is a product of metamorphic action.

Composition.—The earlier analyses, which indicate potash only, and no soda, will be passed over.

* The earlier analyses of orthoclase and albite, which indicated only potash and soda respectively, are obviously inaccurate.

† Mitscherlich.—Lehrbuch der Chemie, ii, 158.

	Analyzed by	O. Q.
I. Adular, from St. Gotthard	.... Awdeëff*	0.331
II. White or grey transparent orthoclase crystals from the protogyn in the Alps	} Delesse †	0.331
III. Orthoclase from the deep Fürstenstollen, near Freiberg	} Kersten ‡	0.334
IV. Orthoclase crystals from Baveno	} Abich §	0.335
V. Grey orthoclase from the Quarryville granite, near Wilmington	} Boyé and Booth ||	0.335
VI. Orthoclase, from Muloe, near Freiberg	} Moll, under Rammelsberg ¶	0.336
VII. Adular from St. Gotthard	.... Abich **	0.337
VIII. Perthite from Bathurst, Canada	} Hunt ††	0.337
IX. Weissigite out of drusy cavities of amygdaloid porphyry, near Weissig, between Dresden and Bauzen ‡‡	}	0.338
X. Amazon-stone, green orthoclase from Siberia; contains some oxide of copper	} Abich §§	0.339
XI. Erythrite from the Kilpatrick Hills, near Glasgow	} Thomson ||| ....	0.341
XII. White orthoclase from granite veins in Delaware	} Boyé & Booth ¶¶	0.349
XIII. Pale greenish grey orthoclase from the zirkonsyenite of Laurvig	} C. G. Gmelin***	0.350

* Poggend. Annal. lii, 467.

† Annal. de Chim. et de physique. 3 Sér. xxv, 14.

‡ Journ für prakt. Chemie, xxxvii, 172.

§ Poggend. Annal. li, 528.

|| Jahrbuch für Mineral. &c. 1845, p. 331.

¶ Handwörterbuch der chem. Mineral. 3^{tes} Supplement, p. 69.

** Loc. cit.

†† Phil. Mag. Ser. 4, i, 322.

‡‡ English edition, ii, 140. This mineral contains some lithium.

§§ Berg and Hüttenmannische Zeitung. Jahrgang, i, No. 19.

||| Phil. Mag. Ser. 3, 1843, p. 188.

¶¶ Loc. cit.

*** Poggend. Annal. lxxxi, 313.

	Analyzed by	O. Q.
XIV. Orthoclase from druses in the granite of Schwartzbach, in the Reissengebirge. It occurs in fine, large, white crystals, which are red on the fractured surface; they frequently have an incrustation of red hydrated peroxide of iron upon the surface, and the lateral faces are covered with transparent crystals of albite	Awdeëff*	.... 0·354
XV. Yellowish white orthoclase from druses in the granite of Alabaschka. Often in very large crystals.	Moss †	.... 0·363
XVI. Reddish orthoclase from the syenite of the Vosges	Delesse ‡	.... 0·364
XVII. Crystallized orthoclase from Bodenmais.	Kerndt §	.... 0·373
XVIII. Orthoclase with blueish tinge, from the zirkon-syenite of Fredriksvärn	C. G. Gmelin ||	0·374
XIX. Flesh-coloured orthoclase, from tin lodes near Marienberg	Kröner ¶	.... 0·318
XX. Orthoclase crystals from the porphyry of Auerberg, in the Harz; somewhat disintegrated and soft	Rammelsberg**	0·310

The oxygen quotients of the first eight minerals are so near 0·333, and even those from IX to XII differ from this value so little that it may be taken as the normal oxygen quotient. In the succeeding minerals the oxygen quotient increases, and reaches

* Loc. cit.

† Poggendorff's Annal. lii, 467.

‡ Annal des Mines. Sér. 4, xiii, 667.

§ Journ. für prakt. Chem. xliii, 207.

|| Loc. cit.

¶ Poggend. Annal. lxxvii, 421.

** Handwörterbuch. 4^{tes}, Supplement, p. 70.

its maximum in XVIII. All the specimens of orthoclase in which the oxygen quotient exceeds the normal value have therefore lost more or less silica, and are in a state of conversion into kaolin. In the decomposed felspar from Carlsbad (VI) the oxygen quotient amounts to 0.554, and in kaolin it is 0.75. In XIX and XX the oxygen quotient is less than the normal value, so that these minerals have lost a portion of their bases by a decomposition of an opposite kind. In XX there is no doubt of this, since the mineral is disintegrated. In the disintegrated felspar from Geising* the oxygen quotient is only 0.263.

As the number of analyses of felspar with high oxygen quotient is much greater than the number of analyses of felspar with low oxygen quotient, it appears unquestionable that in the decomposition of orthoclase the loss of silica is much more frequent than the loss of bases.

The following data will illustrate the alteration of orthoclase.

Percentage composition of normal and altered specimens of orthoclase selected from the previous analyses.

	II.	III.	IV.	XIII.	XVIII.	XX.
Silica	66.48	65.52	65.72	65.90	65.18	66.26
Alumina	19.06	17.61	18.57	19.46	19.99	16.98
Peroxide of iron ....	..	0.80	..	0.44	0.63	0.31
Lime	0.63	0.94	0.34	0.27	0.48	0.43
Magnesia ....	..	..	0.10	..	..	0.11
Potash	10.52	12.98	14.02	6.55	7.03	14.42
Soda	2.30	1.70	1.25	6.14	7.03	0.20
Loss by ignition ....	..	..	..	0.12	0.38	1.29
	98.99	99.55	100.00	98.88	100.77	100.00
O. Q.	0.331	0.334	0.335	0.350	0.374	0.310

It will be seen that the highest and lowest oxygen quotients are accompanied by the presence of water in the minerals, which indicates that decomposition has already commenced. In XIII and XVIII there is an increase, and in XX a decrease in the quantity of alumina, while in the latter mineral, the quantity of alkalies does not appear to have been affected, so that it is evident some alumina has been removed, and that this orthoclase was in a state of decomposition, opposite to the conversion into kaolin.

* See p. 179, No. IV.

It is worth notice that in XVIII the highest amount of soda is accompanied by the highest oxygen quotient.

Formation.—Where orthoclase occurs associated with minerals that can have been formed only in the wet way the possibility of its having been formed by fusion is entirely excluded.

Hausmann* found adular crystals, together with rock crystal, bitter-spar, and iron pyrites on a lode in the Herzog Ulrich mine near Kongsberg. I have seen in the Berlin collection of minerals a specimen from Kongsberg, in which adular is associated with rock crystal and bitter-spar; and another specimen from a lode near Schemnitz in Hungary, which contains crystals of felspar. Wisert† describes two pieces of lode from Schemnitz which contain crystallized adular; in one, a part of the iron pyrites appears to have been formed first, then the felspar and the copper pyrites; in the other specimen felspar and quartz appear to have been formed first, then brown-spar and zincblende, and lastly gold and iron pyrites. Here, therefore, the felspar alternates with minerals that have unquestionably been formed in the wet way, and as in the first named specimen, has even been formed after the iron pyrites with which it is associated.

Foster and Whitney‡ state that orthoclase occurs at the Copper Falls mine, Lake Superior, associated with calcareous spar and native copper. The felspar is evidently posterior in formation to both these substances, and must, therefore, have been formed in the wet way.

Those geologists who admit the force of the arguments that I have brought forward to prove the formation of ores in the wet way, must, to be consistent, recognize the formation of the felspar accompanying those ores in the same manner.

Otto Volger§ found in small drusy cavities, that were very numerous in a rock from St. Gotthard, consisting chiefly of small granules of quartz and albite, transparent crystals of adular from $\frac{1}{4}$ to $\frac{1}{2}$ a line in diameter mixed with quartz crystals, and here and there, between the crystals of adular, crystals of calc-spar more than a line in length. A comparison of the irregular and much altered granules of felspar in this rock with the well-developed crystals of adular in the drusy cavities, renders it

* Reise durch Scandinavien, ii, 22, and Beiträge zur Metallurgischen Krystallkunde.—See also German edition, ii, 330.

† Jahrbuch für Mineral, etc. 1850, p. 429.

‡ Report on the Geology of the Lake Superior district, ii, 102.

§ Studien zur Entwicklungsgeschichte der Mineralien. 1854, pp. 271 and 543.

unquestionable that the latter are of more recent formation. It is probable that these crystals of adular have been formed from water which had extracted the material from the granules of felspar and carried it into the drusy cavities.

The crystals of calc-spar were not found upon the crystals of adular, nor were these found upon the calc-spar. G. Rose* found on the contrary in a specimen from St. Gotthard a fine crystal of adular attached to the surface of crystallized calc-spar. This observation confines Volger's conjecture that the adular crystals were more recently formed than the calc-spar.

In the dolomite of East Bradford, Pennsylvania, there occurs a felspar called chesterlite, which, according to two analyses† by T. Lawrence Smith and T. Brush, is merely orthoclase. Those geologists who regard dolomite as a product of the metamorphosis of limestone by plutonic action, will not hesitate to attribute to this orthoclase the same origin. But it must be remembered that according to Berthier‡ two thirds of the potash in orthoclase is separated when it is melted with an equal weight of carbonate of lime. The occurrence of orthoclase in dolomite would, therefore, show that this rock has not been exposed to any considerable degree of heat. Moreover, it will subsequently be shown that this rock cannot have been produced by the metamorphosis of limestone by heat.

At Steimel near Schameder in the district of the Lenne, Olligschläger found in a schistose felspar-porphry which contained a great number of large, white crystals of felspar, the sheath of a *homalonatus* $2\frac{3}{4}$ inches broad, $2\frac{1}{2}$ inches long, and covered with 11 arched ribs. V. Dechen,§ to whom I am indebted for this fact, infers that the porphyry in which this fossil was found could not have been protruded from the interior of the earth at a high temperature, and have solidified at the surface; because such an origin is incompatible with the presence of any

* Communicated by letter.

† Silliman and Dana's American Journal. Ser. 2, xvi, 41 et seq.—These chemists found 13.86 to 14.18 per cent. potash, and 1.64 to 1.75 per cent. soda.—In Dana's Mineralogy, p. 678, chesterlite is described as a felspar, having the form of albite, with somewhat different angles, which, however, cannot be measured exactly, and containing, according to Erni, 2.84 per cent. potash, with 10.41 per cent. soda, so that it would appear to be really albite, although in the small percentage of silica, 65.53, it does not correspond with that mineral. Either this analysis is incorrect, or this dolomite contains both orthoclase and albite, or the chesterlite analyzed by Erni was a mixture of the two kinds of felspar.

‡ Journ. für prakt. Chemie. vi, 106.

§ Archiv. für Mineral, &c. xix, 367 et seq.

organic substance. Grandjean* found small white crystals, which from their physical characters he considered to be orthoclase, in cavities which had been formed by the removal of carbonate of lime from fossils, in the grauwacke near Lahnstein.

These facts, and in no less degree those stated at pages 140 and 147, as to the occurrence of orthoclase with the forms of zeolites, indicate most positively the formation of this felspar in the wet way. There is very little probability that felspar occurs anywhere under circumstances that would not admit of this origin being attributed to it. Orthoclase has never yet been met with in lava.

The possibility of the formation of this felspar by fusion, cannot, however, be questioned; for it has been found in the form of violet coloured crystals upon the inner walls of a smelting furnace at Sangerhausen. The composition of this substance was according to Heine.†

Silica	....	....	....	65.95
Alumina	....	....	....	18.50
Potash (and perhaps soda)	....	....	....	10.47
Lime	....	....	....	4.28
Peroxide of iron	....	....	....	0.69
Oxide of copper	....	....	....	0.13
Oxides of zinc, manganese, and cobalt	....	....	....	traces
				<hr/>
				100.02
Oxygen quotient	....	....	....	0.346

These crystals have, with the exception of a few accidental admixtures by which they are coloured, a composition quite analogous to that of orthoclase, the only difference being that a little of the potash is replaced by lime. The copper ores that are smelted at Sangerhausen are very rich in carbonate of lime, sometimes they contain alumina and silica likewise. In any case, lime preponderates greatly over the potash, which is, perhaps, derived only from the ash of the charcoal used, and the preponderance of lime in this orthoclase ‡ may be owing to a deficiency of potash in the material from which it was formed. But since the experiments of Berthier, already alluded to, show that when orthoclase is melted with carbonate of lime a portion of its potash is removed, it is also possible that this has taken place in the formation of this orthoclase. The above analysis, however, at least renders it certain

* Loc. cit.

† Poggendorff's Annalen, xxxiv, 542.

‡ According to Rose, the quantity of lime appears not to be uniform in all the crystals, and the quantity of potash decreases as that of lime increases.

that the orthoclase formed by fusion in the presence of carbonate of lime will always contain a larger proportion of lime than usual. It also justifies the remarks previously made as to the formation of the orthoclase from dolomite, analyzed by Smith and Brush, which contained only 0.56 to 0.65 per cent., potash. Therefore it cannot be supposed that orthoclase occurring together with carbonate of lime, as for instance the adular from St. Gotthard, has been formed by fusion.

Hausmann * found very well developed crystals of felspar in cavities of the wall of an iron furnace, near Stollberg in the Harz. They were about 5 feet 8 inches above the bottom, and except in size corresponded perfectly with the adular of St. Gotthard. No analysis was published, and therefore it cannot be determined whether they contained a large amount of lime.

Conversion of one species of felspar into another or decomposition of one species into two others.—The orthoclase crystals in the drusy cavities of granite at the Riesengebirge are generally covered with small, transparent crystals of albite principally upon certain faces, while other faces are sometimes without them. G. Rose † states that the rough disintegrated surfaces of the orthoclase of Lomnitz that has been converted into mica, are also covered with transparent crystals of albite. These albite crystals also occur upon uneven faces which appear as if they had been formed by cracks and rents. It is evident that the orthoclase crystals must have been rent before the albite could have been deposited upon the faces thus formed.

Moreover the orthoclase crystals are very frequently wholly or partially covered with a thin incrustation of earthy peroxide of iron, it is sometimes thick and very often appears as fine scales of specular iron. Albite crystals not unfrequently occur upon this incrustation, especially where the orthoclase presents the above-mentioned irregular faces of fracture. Then the albite crystals are frequently mixed with oxide of iron and are of a red colour. The oxide of iron is dissolved by hydrochloric acid.

As the oxide of iron is situated between the orthoclase and albite, these substances cannot have been formed in immediate succession. G. Rose is of opinion that if, according to my investigations, this oxide of iron was formed in the wet way the same origin may be attributed to the albite. It would appear, therefore, that felspar was originally an intimate mixture of orthoclase and

* Beiträge zur Metallurgischen Krystallkunde, 1850, p. 44.

† Poggendorff's Annalen, lxxx, 123.

albite, from which water gradually extracted the latter and deposited it upon the surface of the felspar. The analysis of the orthoclase of Schwarzbach* shows that this extraction is not yet completed, for this mineral contains as much as 5.06 per cent. of soda although G. Rose was unable to detect any admixture of albite previous to analysis. Moreover the high percentage of silica 67.20, which is 2.00 per cent. greater than in orthoclase and 2.00 per cent. less than in albite, would indicate that it is a mixture of orthoclase and albite. Volger† gives a description of the orthoclase at Baveno which is covered on all its faces with a crust of albite. The crystals of orthoclase are very much altered and some of the faces are quite disintegrated, while on the contrary the albite is perfectly unaltered, and evidently of recent formation. Orthoclase, with such a large proportion of soda as XIII and XVIII,‡ would yield material for the formation of albite when undergoing decomposition; and this large proportion of soda would in itself render it especially liable to alteration.

Wiser§ describes a specimen which contains epidote with adular, apatite, chlorite, mica and small white crystals of albite(?) and in which the adular crystals consist of a greyish, transparent nucleus with a thin, yellowish translucent crust; while the epidote apatite, and particularly the questionable albite, crystals are perfectly unaltered. Sometimes the adular crystals are quite hollow. Volger states that on the surfaces of a fissure in this specimen the same minerals occur in well developed crystals among which the adular crystals are covered on the prism faces with a dirty yellowish white crust from 0.5 to 1.5 millimeter thick, and contain a roughened transparent nucleus; milk white shining crystals of albite from 0.25 to 3.00 millimeter in size are scattered over the entire surfaces of the fissure. In all parts there are groups of the adular crystals which form the nuclei in the surfaces of the fissure and in some places they are blended with the remains of a crystal. They are surrounded by a white granular felspar mass into which they pass irregularly.

In a second specimen from the south side of St. Gotthard, Wiser|| found the adular crystals partly porous, partly so perfectly hollow as to present merely thin shells, which by the destruction of the terminal faces are quite open. No trace of the

* English edition, ii, 160, No. xiv.

† Loc. cit. p. 213.

‡ English edition, ii, 159, 160.

§ Jahrbuch für Mineral. etc. 1844, p. 156, and Volger—loc. cit. p. 192.

|| Loc. cit. p. 199.

adular remains; the hollow shells which correspond perfectly with the crusts of the adular crystals in the previous specimen are milk white, and consist of pure tetartine, with innumerable small crystals of tetartine. The principal mass of the specimen is indeed granular tetartine intimately blended with the shells presenting the form of the adular crystals.

There is no doubt that both specimens come from the same rock; the only difference being that the process of alteration was less advanced in the former than in the latter specimen, or rather that in this, it was completed. Two other specimens from St. Gotthard presented similar characters.*

Another specimen in Wiser's collection, from the micaceous schist of Peccia in the Maggia valley,† shows that such alterations as the above are not confined to St. Gotthard. This specimen, which differs considerably from the former ones, consists of a very fine grained felspar matrix, in which, by the aid of the microscope, colourless semi-transparent and opaque white granules could be detected. Volger conjectures that the former is adular, and that the latter is tetartine. Upon the surface of a druse there are adular crystals that are not yet fully decomposed; most of them are however, completely, and all the rest partially, converted into tetartine. At the interior of some crystals, which are altered to a certain depth, there is a mixture of milk white porous tetartine, and semi-transparent granules of adular. The following analyses furnish an insight into the chemical relations of the mineral alterations that have taken place at St. Gotthard; VII and I are analyses of adular from St. Gotthard‡; XVIII, the analysis of crystallized pericline by Thaulow;§ X, the analysis of the albite subsequently to be mentioned; both are from St. Gotthard.

	VII.	I.	XVIII.	X.
Silica	65.69	65.75	69.00	67.39
Alumina	17.97	18.28	19.43	19.24
Lime	1.34	trace	0.20	0.31
Magnesia ....	...	trace	...	0.61
Kali	13.99	14.17	...	6.77
Soda	1.01	1.44	11.47	6.23
	100.00	99.64	100.10	100.55
O. Q.	0.337	0.331	0.336	0.346

* Loc. cit. p. 206.

† Loc. cit. p. 206.

‡ English edition, ii, 150.

§ Poggendorff's Annalen, xlii, 574.

In the analysis VII and XVIII, the greatest care was taken in the separation of the potash and soda; in the analyses I and X this is not less to be expected, as they were made under the direction of H. Rose.

The specimens of adular VII and I are characterized by a very small proportion of soda, and the albite XVIII is quite free from potash.

The albite X differs widely from XVIII, the amount of potash being even greater than that of soda. In the communication of this analysis it was remarked that the mineral was probably a mixture of albite and orthoclase, especially as the re-entering angles of the cleavage planes cannot always be recognized. The albite XVIII is of the purest kind. This is further evidenced by the distinct crystalline form which it presents, while, on the contrary, X is white and granular, and presents the appearance which Volger describes as characteristic of the transition of adular into albite.*

Assuming that X consists of a mixture of adular having the composition VII, with albite having the composition XVIII, it would follow that X contains 54 per cent. adular, and 46 per cent. albite.

Calculating the composition of X according to this assumption, the following result is obtained:—

	55 per cent.		46 per cent.	
Silica 35.47	} + {	31.74	} = {
Alumina	.... 9.70		8.84
Lime	.... 0.72		0.09
Potash	.... 7.55		...
Soda	.... 0.55		5.28
	<hr/> 53.99		<hr/> 46.05	<hr/> 100.04

When the calculation is based upon that of I, the approximative composition of X would be 54 per cent. adular, and 45.3 albite as follows:—

	54 per cent.		45.3 per cent.	
Silica 35.97	} + {	31.26	} = {
Alumina	.... 10.00		8.80
Lime	.... ...		0.09
Potash	.... 7.75		...
Soda	.... 0.79		5.20
	<hr/> 54.51		<hr/> 45.35	<hr/> 99.86

* It would be very interesting if a sufficient quantity of the albite granules of the specimen from St. Gotthard could be collected and submitted to chemical analysis, in order to determine whether it contains as much potash as X.

Both calculations give a composition for X which corresponds so closely with that found by analysis, that the above assumptions appear to be well founded

Assuming that the hollow adular crystals that have been perfectly converted into tetartine* had the composition VII or I, and that the tetartine has the composition XVIII, then the whole of the potash must have been removed, together with as much silica, alumina, and lime as might be requisite, so as to leave a residue having the composition XVIII. It is upon this assumption that the following calculation is based.

	VII.		A.		B.	C.
Silica	65.69	—	6.07	=	59.62	65.38
Alumina	17.97	—	1.71	=	16.26	17.83
Lime	1.34	—	0.02	=	1.32	1.45
Potash	13.99	—	0.00	=	13.99	15.34
Soda	1.01	—	1.01	=	0.00	...
	<hr/> 100.00		<hr/> 8.81		<hr/> 91.19	<hr/> 100.00

VII represents the composition of the adular previously referred to; A, the residue that would be left after the removal of the felspar substance B from the albite XVIII; C is the percentage composition of B.

When the calculation is based upon the adular I, the result is as follows:—

	I.		A.		B.	C.
Silica	65.75	—	8.66	=	57.09	65.54
Alumina	18.28	—	2.44	=	15.84	18.19
Lime	trace	—	0.03	=	0.03	...
Potash	14.17	—	0.00	=	14.17	16.27
Soda	1.44	—	1.44	=	0.00	...
	<hr/> 99.64		<hr/> 12.57		<hr/> 87.07	<hr/> 100.00

I is the composition of the adular; B represents the substance removed; A the residue, and C the percentage composition of B.

In both calculations, C corresponds so closely with the theoretical composition of orthoclase, that there can be no difficulty in supposing that adular may be decomposed into orthoclase free from soda, and albite free from potash. The former product which is removed by water would amount to 91.19, or 87.07 per cent., and the latter product which remains would amount to 8.81, or 12.57 per cent. The origin of the thin shell, consisting of albite, which remains after the entire decomposition of the adular, is in this way fully accounted for.

* English edition, ii, 167.

In those adular crystals which are porous,* the decomposition and removal of the orthoclase substance has not advanced so far as in those which are perfectly hollow. This removal of orthoclase substance would appear to be accompanied by a contraction of the albite substance owing to molecular attraction; for if this were not the case, an extremely porous skeleton of albite would remain, and the shell of albite would not have been formed. Those adular crystals which consist of a transparent nucleus and a thin crust† are certainly in the earlier stage of decomposition, and the orthoclase substance has been removed from them only at the exterior parts.

The above described pseudomorphs, consisting of albite with the form of adular, are certainly among the most interesting that are known, and no little merit is due to Volger for carrying out the investigation that has led to such valuable results. Whether we regard the decomposed adular as having been originally a mixture of potash and of soda feldspars, or as an homogeneous mineral, it would still be very remarkable that, in the first case, the one of two such similar substances, as these two feldspars are, should be extracted while the other remains; or, that, in the second case, water should in the first instance effect a decomposition of the mineral into two others, of which it subsequently removes one and leaves the other. Whether in either case the orthoclase substance is removed directly, or whether it is previously decomposed by the action of carbonic acid in the water, cannot be determined.

Many instances are known of the increase or diminution of the solubility of a substance when some other substance is present in the solvent.‡ It is, therefore, possible that water exercises a different solvent action upon mineral substances when pure, and when it contains other substances in solution. The unequal action of water upon different mineral substances is, however, mostly a consequence of its containing in solution substances which exert a decomposing action upon some minerals, but not upon others. Chloride of sodium decomposes silicate of potash, chloride of potassium and silicate of soda being formed.§ Therefore water containing chloride of sodium may cause the decomposition of potash felspar, while it leaves soda felspar unaltered.

* English edition, ii, 167.

† See ante, p. 166.

‡ A striking instance of this kind has already been pointed out.—i, 406.

§ English edition, i, 12, No. 9.

Hence it is possible that by the action of such water, either potash felspar may be converted into soda felspar, or that the products of the decomposition may be dissolved by the water and removed. It is, therefore, admissible to suppose that water containing this substance, which is almost always present in water, has decomposed the silicate of potash in adular, removing the silicate of soda formed, together with the silicate of alumina associated with it, while the silicate of soda and the remainder of the silicate of alumina combined with it have not been acted upon.

On the other hand, carbonate of potash decomposes silicate of soda.* Hence it is possible that water containing carbonate of potash may either effect the conversion of soda felspar into potash felspar, or that it may dissolve the products of the decomposition and remove them. Water of this kind would, therefore, produce an effect opposite to that produced in the former case.

The rocks at St. Gotthard, which present the above described pseudomorphs, have long been numbered among metamorphic rocks; but geologists ascribed their metamorphism to the influence of heat. But even if the source of heat were recognizable, there does not seem to be any possibility of accounting for the decompositions that have taken place in these small crystals, and for the removal of products of decomposition in this way. It cannot be supposed that orthoclase substance could be separated from adular crystals and removed by sublimation, while the albite substance was left; and there is no other mode of removal than sublimation to which this metamorphism can be ascribed by those who hold plutonic views.

It is questionable whether the removal of potash felspar has been a general phenomenon throughout the whole of the St. Gotthard, or whether there may not likewise have been a conversion of potash felspar into soda felspar. In the case of the hollow adular crystals the former action alone appears to have taken place, although it cannot be determined whether at least a portion of the adular has, or has not, been converted into albite. Volger remarks that it is evident there has been much more adular decomposed than albite formed.†

* See ante, p. 65, No. 38.

† As the formation of epidote is intimately connected with the decomposition of adular, Volger raises the question, whether a portion of the products of the decomposition of the adular may not perhaps have furnished the material for the formation of epidote. In any case this could only have been the result of a very complicated process, and the danger of forming erroneous opinions increases in proportion to the assumption of such processes.

The albite crystals upon orthoclase,* show, according to the view of G. Rose, that soda felspar may be removed from orthoclase while the potash felspar remains unaltered. Such dissimilar effects unquestionably presuppose causes that are at least different if not opposite in their nature, that is to say, the presence of different substances in the water by which they were produced.

Lastly, the above-mentioned† adular crystals in the druses of the rock containing older albite show that potash felspar may be separated from this mineral; a result which presupposes that the albite was not free from potash like III, but that, as is generally the case, it contained some potash. Volger‡ found, upon a subsequent examination of Wiser's collection, that alteration pseudomorphs of adular with the form of pericline are more frequent than unaltered pericline.

The conversion of leucite into glassy felspar will be treated of subsequently.

Mica with the form of felspar.—Haidinger and Blum observed this pseudomorph in the felspar of St. Agnes and St. Just, in Cornwall.§ A twin crystal of felspar from decomposed granite, near a tin lode at St. Just, consisted of an extremely fine granular mixture of white mica and quartz, in which granules of tin ore were disseminated. Since the conversion of felspar into mica would be attended with separation of silica, the presence of the quartz is particularly interesting.

Blum found a still more characteristic specimen of the conversion of felspar into mica in the granite of Warmsteinach in the Fichtelgebirge, which consists almost entirely of felspar and quartz with very little mica. The felspar is almost everywhere mixed with very small greenish white scales of mica, which at some places almost entirely occupy the place of the felspar, sometimes present the crystalline form of the felspar distinctly and well preserved. The alteration commences at the exterior, and sometimes nuclei of unaltered felspar are found imbedded in the mica. It is extremely remarkable that sometimes crystals which have been entirely altered are found imbedded in the crystalline felspar presenting this alteration and distinctly separated from it.||

A very remarkable pseudomorph from drusy cavities in the

* See ante, p. 165.

† See ante, p. 167.

‡ Loc. cit. p. 547.

§ Erster Nachtrag, p. 25.

|| German edition, ii, 303.

granite of Lomnitz in Silesia, is described by G. Rose.* The surface of the felspar is rough and disintegrated, and covered with laminæ of mica more or less thickly. The mica substance generally extends inwards in the direction of small fissures, and sometimes the interior is filled with mica so that no trace of the felspar can be recognized by means of a magnifying glass. Rose agrees with me in the opinion, that this alteration can only have taken place in the wet way. As in this pseudomorph and in the previous one there is no quartz, the silica separated must have been removed by water.

Blum † describes a specimen presenting a conversion of felspar into steatite(?) from the granite near Finbo in Sweden. The crystalline masses of felspar as well as the individual crystals consist of a mixture of steatite(?) with quartz and mica. It is only at some few parts that felspar can be recognized, and there it is somewhat altered. The alteration commenced at the exterior, but not uniformly over the surface. Where it was completed, the mass was very soft, yellowish-white or olive-green; while at other parts where it was harder, the colour was reddish white. The same characters were apparent at the interior. The cleavage had been entirely lost.

The mica and quartz likewise present indications of alteration. The former is less brittle, much softer than usual, and admits of being easily split into thin laminæ. The quartz at the point of contact with the altered felspar appears somewhat more brittle.

The analysis of this pseudomorph ‡ shows how readily even practised mineralogists may be deceived as to the nature of substances by mineralogical characters; for it turns out that this mineral does not contain a particle of steatite. The product of the alteration is nothing else than mica in an imperfect state.

The inferences that may be drawn from the results of this analysis, and from the analysis of the mica occurring with the form of felspar at Wurmesteyn, in reference to the process of alteration will be treated of subsequently.

Chlorite with the form of felspar.—Fine specimens of this pseudomorph are found at Berggiesshübel in Saxony, in a bed of magnetic iron ore in clay slate, and have been described by Blum.§ The white or flesh coloured felspar is dull and grey colored at the surface where the alteration has taken place. Minute scales of

* Zeitschrift der Deutschen Geologischen Gesellschaft, ii, 10.

† Erster Nachtrag, p. 71.

‡ See Chapter xxxviii, No. III.

§ Erster Nachtrag, p. 85.

chlorite make their appearance, increasing in quantity, until a perfect crust of chlorite is formed. On breaking these crystals the different stages of the progress of the alteration inwards become apparent. While in some instances the crust has been formed, in others the chlorite appears in very fine laminæ in the felspar matrix, especially in the direction of the cleavage planes, and sometimes in such quantity that there is a complete mixture of the two substances. In other specimens there is only a very small nucleus of felspar; it very rarely occurs that this has entirely disappeared, in which case the crystals consist of a fine grained aggregate of chlorite.

In the conversion of felspar into chlorite there must have been a substitution of protosilicate of iron and silicate of magnesia in the place of alkaline silicates, and an introduction of water. As the magnesia and protoxide of iron in chlorite amount to twice as much as the alkalies in felspar, while the silica in the former is less than half as much as in the latter there must have been nearly as much silica removed during the alteration as there was magnesia and protoxide of iron introduced, for the description of the pseudomorphs shows that the volume has not been increased by the alteration. There was, however, an increase of mass, for the specific gravity of the chlorite is greater than that of felspar. This increase cannot be taken into account, as the specific gravity of the products of alteration is not known, and that of chlorite varies greatly. Since, however, besides magnesia and protoxide of iron, about 12 per cent. of water was introduced, it cannot be doubted that silica was removed. The alumina in chlorite is only about 1 per cent. less than in felspar, so that only a small portion of it can have been separated.

As alkaline silicates are decomposed by bicarbonate of magnesia, and alkaline carbonates formed,* it may be supposed that water containing bicarbonate of magnesia would convert the alkaline silicates into silicate of magnesia and remove the alkaline carbonates. But, at the same time, the excess of silica must have been removed; so that the neutral silicates of the felspar might be converted into the basic silicates of the chlorite. Lastly, as hydrated peroxide of iron decomposed silicate of alumina,† the partial displacement of alumina by oxide of iron is likewise accounted for. It may therefore be supposed, that water, containing besides bicarbonate of magnesia some protocarbonate of iron, might have effected the conversion of felspar into chlorite. Further elucidation of this

* See ante, p. 69, No. 46.

† See ante, p. 74, No. 49.

process of alteration is to be expected from the chemical examination of the chlorite formed from this felspar and the determination of its specific gravity.

Tin ore with the form of felspar.—This pseudomorph was first observed by J. Davy,* at the Huel Coates mines, near St. Agnes' Beacon, in Cornwall. The crystals consist of a fine grained aggregate of tin ore, generally mixed with more or less quartz in granules. The surface of the crystals is granular, rough and uneven, more particularly when the aggregate consists of coarser granules. The crystals are not unfrequently rent and cemented together again by small crystals of tin ore. Some of the crystals are said by Anker† to be entirely tin ore at the middle, while the two ends consist of pure felspar. Blum‡ describes a twin felspar crystal that is entirely altered in its substance, and consists of a very fine grained mixture of white mica and quartz, through which granules of tin ore are disseminated. There would appear in this instance to have been a conversion of the felspar into quartz and mica, and at the same time a penetration of tin ore. This crystal is from St. Just in Cornwall, but its appearance is quite analogous to that of the crystals from Huel Coates. These crystals are abundant in a decomposed granite near a tin lode, by which it is traversed.

The quartz granules likewise appear in a specimen from St. Agnes, which gave the following results (I) on analysis. When immersed in very dilute hydrochloric acid, there is a scanty evolution of gas bubbles, and the liquid shows traces of lime.

This specimen, which was somewhat friable, was analyzed by Kjerulf in my laboratory, and the alkalies were separately estimated by myself.

				I.	II.		
Silica	25.49	+ 0.41 } + 3.17 }	47 felspar substance.	
Alumina	....	....	....	6.65
Potash	....	....	....	3.00
Soda ...	....	....	....	0.33
Peroxide of iron	9.82	61.36 impure tin ore.	
Oxide of manganese and magnesia....	....	....	....	2.14
Oxide of tin	....	....	....	47.82
Loss by ignition	....	....	....	1.58
				96.83	§		

* Transact. of the Royal Geological Society of Cornwall, iv, 484.

† Annales des Mines. Sér. 3, xx, 110.

‡ Die Pseudomorphosen, p. 275.

§ On account of the deficiency of material the analysis could not be repeated, and the considerable deficiency of 3.17 per cent. cannot be accounted for.

Under II are given the quantities of alumina and of alkalis that must be added to the quantities found by analysis, in order to represent a substance having the composition of normal orthoclase. We must, therefore, suppose that nearly two-thirds of the original felspar substance has been displaced by the oxide of tin, and the substances associated with it, and that from the remainder, alumina and alkalis have been separated in the above proportions, so that there was at the same time displacement and partial decomposition going on. On the contrary, in those pseudomorphs which contain quartz, the decomposition of the felspar appears to have progressed to such an extent, as to cause the separation of the silica as quartz. When mica is associated with the quartz, there is good reason for supposing that these substances are products of the decomposition of the felspar.

The analyses given below of decomposed felspar from Ilmenau, show that there has been a total displacement of felspar substance by lime, and bicarbonate of iron. It is possible that in the formation of the above-mentioned pseudomorphs, the removal of the felspar substance was effected by these bicarbonates, and that the carbonate of lime deposited was subsequently removed by water, leaving merely an inconsiderable amount of peroxide of iron. Perhaps the minute quantity of carbonate of lime in the specimen examined was the residue of this carbonate. The deposition of the tin ore from water may be accounted for without difficulty, since, as I shall subsequently have occasion to show, the oxide of tin is soluble in solution of carbonate of potash.

Blum* describes specimens presenting alterations of felspar and of couzeranite into talc, consisting of fine laminae and scales. In the latter case, when the process of alteration is incomplete, there is a mixture of couzeranite and talc; when, however, the alteration is complete, the crystals consist entirely of talc laminae. This pseudomorph is very rare, and I have not had any opportunity of ascertaining whether the product of alteration is really talc.

Kaolin with the form of felspar.—The conversion of felspar into kaolin is of very frequent occurrence.† The alteration generally commences at the exterior and progresses inwards; the

* Die Pseudomorphosen, p. 109, and Erster Nachtrag, p. 65.

† Since kaolin appears to be only a product of the alteration of other minerals, and in no instance as an individual mineral, it must be regarded as a product of decomposition, more especially since the form of the mineral from which it may have been derived is entirely lost when the decomposition is complete.

contrary is seldom observed. Sometimes decomposed felspar crystals are situated close beside others that are not at all altered. When the alteration commences at the exterior, the crystals at first become dull, and the flesh colour passes into yellowish white. An earthy crust is formed, which gradually becomes thicker as the alteration progresses. The progress of the alteration is not always uniform, and there are frequently found in the interior of the decomposed crystals several solid unaltered particles separated from each other by layers of the earthy product of decomposition. The cleavage, hardness, and coherence of the felspar are entirely lost, and the specific gravity is reduced as much as 14 per cent.

This alteration consists essentially in the removal of the alkalies, together with a portion of silica, while water is introduced into the mass. The loss of silica always amounts to more than that of alkalies, for the oxygen quotient is increased. Out of more than 25 analyses of kaolin, the greater portion show the presence of some alkalies, and since traces of alkalies so readily escape notice in analysis, unless particular attention is directed to their detection, it may be regarded as certain, that in most instances the alteration has not been completed. It is from the same circumstance that the amount of silica varies between 40 and 58 per cent., and that of alumina between 26 and 45 per cent. The normal composition of kaolin, as estimated by Forchhammer* from the analysis of seven specimens, must, therefore, be regarded as merely approximative.

Silica	....	....	....	47·03
Alumina	....	....	....	39·23
Water	...	....	...	13·74
				<hr/>
				100·00
O. Q.	...	...	....	0·75

Since orthoclase, as well as the other feldspars, are anhydrous when in an unaltered state, while kaolin is hydrated, the alteration of the one into the other bears a direct relation to the introduction of water. More recent analyses of kaolin that has originated from other minerals, such as beryl, according to Damour;† topaz, according to W. S. Clark,‡ correspond very closely with the kaolin from felspar; this product of decomposition would, therefore, appear to be always the same, while the substances separated

* Poggend. Annal. xxxv. 331.

† Bullet. géol. Sér. 2, vii, 224.

‡ Annal. der Chemie und Pharmacie, lxxx, 122.

would differ as much as the minerals which underwent this conversion into kaolin.

The greater the quantity of undecomposed alkaline silicates in kaolin, the greater is the quantity of silica obtained in analysis; consequently, when the percentage of silica is large, it may be inferred that the amount of alkalies is also large.

The following analyses of decomposed feldspars furnish further elucidation of their conversion into kaolin :—

				I.		
				a.	b.	c.
Silica ....	....	...	...	64·00	67·10	9·60
Alumina ....	....	...	...	19·43	17·83	19·30
Potash ....	....	...	...	14·81	13·50	1·32
Lime ....	...	....	....	0·42	0·50	
Magnesia ....	....	....	....	0·20	trace.	Residue. 56·79
Water and loss ....	....	....	....	1·14	1·07	Water. 12·03
				100·00	100·00	99·04

				II.			III.
				a.	b.	c.	
Silica ....	....	...	....	48·13	66·00	63·69	62·23
Alumina ...	....	....	....	34·57	17·59	20·07	5·03
Alkaline earths ....	....	...	...	5·11	Potash 15·00	...	1·60
					Magnesia 0·38		
					Lime 0·40		
Peroxide of iron ....	....	...	....	....	....	....	4·29
Oxide of manganese ....	....	....	....	....	....	....	3·42
Residue ....	....	....	....	....	....	....	8·39
Water ....	....	....	...	13·55	....	....	11·95
				101·36	99·37	....	98·46

I. Moonstone, from Ceylon, in different stages of decomposition ;—*a*, brittle, but still translucent and crystallized; *b*, still more friable and milk white;—*c*, quite decomposed, and converted into a white earthy mass mixed with quartz.

II. Moonstone, from Aue, consisting of *a*, 14·46 per cent. sub-

stance decomposable by acids; and *b*, 85.54 per cent. undecomposable by acids; *c*, the mineral as a whole.

III. Moonstone from Bilin. The most pulverulent part was analyzed by Brongniart and Malaguti.*

I, *a* appears to be orthoclase, that has been little altered. I, *b*, contains some quartz; I, *c*, still more.

II, *a*, approximates in composition to kaolin; II, *b*, is orthoclase, but little altered; II, *c*, shows that disintegrated felspar may have nearly its original composition, while it contains 14.46 per cent. of kaolin substance. As the silica and alumina in II, *c*, and in I, *a*, correspond so closely, I, *a*, may likewise contain as much kaolin substance as the former. But this can be the case only if the silica, separated by decomposition, has not been removed to any great extent.

III, which was obtained from felspar by powdering and washing, is evidently a product of decomposition. Only a small portion of the considerable amount of silica can be combined with the small quantity of bases, and the greater portion must be in the free state. The considerable quantities of peroxides of iron and manganese cannot originate from the decomposed felspar; but were most probably deposited by the water which effected the decomposition, in consequence of the oxidation of carbonates of iron and manganese contained in it; while at the same time alkalies were removed by this water from the felspar.

	IV.	V. <i>a</i>	V. <i>b</i>	VI.	VII.	VIII.
Silica	70.79	63.73	..	54.17	51.56	53.32
Alumina	17.09	15.98	3.27	29.94	28.59	33.60
Peroxide of iron	1.16	4.84	3.36	1.22	5.08	3.83
Lime	0.35	0.65	0.65	0.59	..	..
Magnesia	0.65	0.18	0.06	0.46	0.90	1.30
Potash	5.86	} 14.62		4.67	} 8.09	3.00 †
Soda	0.38			0.41		
Water	3.67			8.51		
	99.95	100.00		99.97	100.00	100.00
O. Q.	0.263			0.554		

IV. Disintegrated felspar from the syenite of Geising, near Altenberg, Crasso.‡

* Poggend. Annal. lx. 89 et seq.

† The material of V, VII, and VIII was not sufficient for a second analysis for the estimation of alkalies, so that they were estimated from the deficiency.

‡ Poggend. Annal. xl, 381, and Rammelsberg's Handwörterbuch, i, 235.

V, *a*. Disintegrated felspar from the porphyry of Leimbuhl, near Elgersburg, analyzed by myself. The crystals had the form of felspar, but the edges and corners were somewhat rounded. The substance was reddish-yellow and yellowish-brown colored, and in some places green; the powder was ochre-brown; it effervesced with acids.

V, *b*. The portion extracted from this felspar by digestion with hydrochloric acid. The silica of this substance was not estimated specially, but only in the analysis of the entire mass V, *a*.

VI. Decomposed felspar from the granite of Carlsbad; Crasso.

VII. Decomposed felspar in twin crystals from Carlsbad.

VIII. Decomposed felspar from Raubschlösschen, near Weinheim.

These two products of decomposition give off a considerable amount of water at 212° F., so that, besides the chemically combined water, there was a quantity of hygroscopic water, and in it a means of producing further decomposition. These two analyses are by myself.

The decomposed felspars, IV and V, unquestionably contain free silica; it has, however, been entirely, or for the most part, removed from VI, VII, and VIII. The last three felspars approximate to the normal composition of kaolin, and it may readily be supposed that if the decomposition were continued, and the remaining alkaline silicates were removed, together with some of the silica from the silicate of alumina, kaolin would be formed. The decomposed felspars IV and V, *a* differ so widely in composition from true kaolin, that there is scarcely any probability that pure kaolin would ever be formed from them. More than half the alkalies have already been removed from IV, and if, during the long period in which this was effected, no silica, or at most only a very small proportion of the silica, could be removed, it is very doubtful whether this could be effected subsequently, because the silica separated had long passed into the insoluble modification. In IV and V, therefore, the decomposition, already alluded to,* which consists in loss of bases has taken place.

G. Wolff† analyzed seven specimens of perfectly decomposed felspar from the so-called "Knollensteinen" which occur near Halle. They presented a tolerable degree of correspondence in composition; the silica amounted to 41.74, or 44.01 per cent.;

* See ante, p. 161.

† Journ. für prakt. Chemie, xxxiv. p. 221.

the alumina to 41·01, or 44·36 per cent.; the water to 10·85, or 13·40 per cent., independently of minute quantities of other bases. These characters approximate somewhat to the above-mentioned composition of kaolin.

The previous analyses of decomposed orthoclase, and many others likewise, confirm the observation already made* that in the decomposition of this felspar there is much more frequently a loss of silica than of bases.

Some twenty-eight years since, I showed that carbonic acid and water determine the decomposition of felspar.† Forchhammer‡ considers the conversion of felspar into kaolin to be a simple decomposition of the former into the latter, and a soluble silicate of potash which is removed by water, while the insoluble kaolin is left. Fournet holds the singular opinion that the disintegration of minerals is chiefly dependent upon their tendency to dimorphism, and that their mechanical disintegration is followed by a chemical alteration effected especially by carbonic acid. Brongniart and Malaguti§ consider that electrical agency is most probably the cause of the decomposition of felspar.

These views are partly one-sided, and partly inadequate. The presence of alkaline carbonates in the water of springs, rich in carbonic acid, shows|| that it is principally carbonic acid that decomposes felspar, and all minerals containing alkalies. The proportion of the carbonate of soda¶ formed in this way, to the silica that would be separated when the conversion of felspar into kaolin was complete, is 1 : 2·3, so that in the water of springs there should be 2·3 times as much silica as carbonate of soda, if these substances originated from felspar by such a perfect decomposition. Out of 38 carbonated springs in the neighbourhood of the Lake of Laach, in the Eifel district, and in Nassau, the water of which I have analysed** there is, however, not one in which these substances bear the above proportion to each other. There is only one instance in which the silica amounts to as much as the carbonate of soda: in the rest it amounts to only $\frac{1}{3}$ or $\frac{1}{2\frac{1}{8}}$ of the latter. Therefore none of the felspar substances which yield carbonate of soda and silica to the water of these springs can be

* See ante, p. 161.

† Bischof.—Die vulcanischen Mineralquellen. Bonn. 1826, p. 298 et seq.

‡ Poggendorff's Annalen, xxxv, 331, et seq.

§ Loc. cit.

|| English edition, i, 1.

¶ The calculation refers to carbonate of soda, because this carbonate occurs more frequently than carbonate of potash in the water of springs.

** German edition, i, 357 et seq.

converted into pure kaolin, but into a mixture of it with quartz. As the carbonate of soda was not estimated directly in the analyses of the water of these springs, more or less of the silica present may be combined with soda; but this alters the view of the case but little, since the silica in most instances amounts to only a small fraction of the carbonate of soda.

All these springs rise from transition rocks. Therefore at the place where their water becomes impregnated with mineral substances, the felspar mass of the rock must be converted into silicate of alumina, mixed with more or less free silica, so that a clay-slate free from uncombined silica, would, by the action of carbonated water, eventually be converted into quartzose slate, or grauwacke.

It is easy to form a conception of the magnitude of this process of decomposition, from the fact that 1000 pounds of the water from one of these springs, containing as a minimum only 1·3 pounds of carbonate of soda, would presuppose the perfect decomposition of 6·5 pounds of soda felspar. A spring similar to that previously described* which yields in twenty-four hours, 11·57 cubic feet, or 76,362 pounds of water, would, therefore, indicate the decomposition, during the same period, of 49·6 pounds of soda felspar, consequently in a year, 18,104 pounds, in order to obtain the quantity of carbonate of soda that its water contains. Then since the quantity of carbonate of soda in the waters of some other springs amounts to from 34 to 13 times as much as in the above instance, since, moreover, the number of these springs in the neighbourhood of the Lake of Laach is almost inestimable,† and since these springs have perhaps been in existence for millions of years, it is easy to imagine what an enormous process of decomposition must have gone on, and still be going on, in the clay-slate of that district.

The alkaline carbonates originating from the decomposition of felspar by water saturated with carbonic acid, are among the most soluble substances known; the carbonate of soda requires for solution only six times its weight of water at the ordinary temperature. On the contrary, silica even in its most soluble form requires 10,000 times its weight of water for solution.‡ If,

* English edition, i, 229.

† Ibid. 217.

‡ This is the largest quantity of silica found in the water of cold carbonated springs in Germany, in the Schier spring near Carlsbad, according to Berzelius, and in the Stahlquelle at Roisdorf, according to my own analyses. Generally, the quantity of silica is much less than $\frac{1}{1000}$, and is sometimes only one-fourth as much.

therefore, the decomposition of felspar by such carbonated water were ever so energetic, there would be sufficient water for the solution of the carbonate of soda formed. But if the silica separated meanwhile amounted to more than $\frac{1}{10000}$ of the water present, the excess could not be dissolved, but would remain mixed with the kaolin.

The case is very different when the decomposition of felspar is effected by fresh water containing only the minute quantity of carbonic acid derived from the atmosphere. By the action of such water, only very small quantities of alkaline carbonates are formed; consequently it is possible that the silica separated at the same time, also small in quantity, may find enough water for solution. In such cases the whole of this silica would be removed with the alkaline carbonates, and pure kaolin would be left. Such an action as this does not, however, appear to take place; for the purest of the specimens of kaolin analyzed by Forchhammer contained an admixture of 6 per cent. quartz sand. This was likewise found to be the case by Brongniart and Malaguti.

The beds of kaolin in granite, the principal situation in which it is found, are certainly not the products of the decomposition of felspar by means of water saturated with carbonic acid; for neither carbonated springs nor exhalations of carbonic acid are known to originate from granite. It must, therefore, have been the surface water filtering through granite which, by means of the minute quantity of carbonic acid that it contains, has effected the decomposition of the felspar. When the kaolin in granite contains an admixture of quartz, this proves that even the minute quantity of carbonic acid in this water decomposed a greater quantity of alkaline silicates, and separated more silica than could be dissolved by the water and removed.

It follows from this consideration that in the decomposition of felspar into kaolin more of the silica separated remains mixed with the kaolin formed, the greater the quantity of carbonic acid in the water, and that, perhaps, the amount of carbonic acid in water is never so small that the whole of the silica separated in the decomposition of felspar can be removed.

The analysis of the fresh water of springs rising from granite would be of particular interest in regard to the relative proportion of silica and alkaline carbonates. It can scarcely be doubted that the latter substances are present in this water, unless earthy salts that would decompose them were dissolved at the same time. If the silica should amount to about 2·3 times as much as the alkaline

carbonates,* the formation of pure kaolin might be supposed to take place. If on the contrary the quantity of silica is less than 2·3 times as much as the alkaline carbonates, it would follow that a quartzose kaolin was being formed.

By reference to the above analyses of decomposed felspar it will be seen that in the pulverulent portion of III, which appears to be a mixture of some kaolin with a large proportion of free silica, this silica has not been converted into quartz granules but is in the state of a fine powder. The decomposed felspars IV and VI contain nearly the same quantity of alkalies, and hence it may be inferred that they are in about the same stage of decomposition; but the very dissimilar quantities of silica show that the course of the decomposition in the two cases was very different. This difference would be easily accounted for on the assumption that IV had been exposed to the action of water richer in carbonic acid, than that by which the decomposition of VI was effected, and that the decomposition had consequently been more energetic, and a smaller proportion of the silica separated had been removed, in the former case, than in the latter. Similar relations appear to have obtained in the decomposition of the felspar V, and that of the felspars VII and VIII.

Decomposition of felspar by carbonates of lime and of iron.—The products of this decomposition occur in the red porphyry of Ilmenau, and were analyzed by G. Crasso.†

Portion soluble in hydrochloric acid 32·1 per cent.
 „ insoluble „ „ 67·2 „

	IX.	X.	XI.
Silica	23·17	69·00	72·16
Alumina ...	7·30	21·74	18·42
Protoxide of manganese	0·17	0·51	...
Magnesia	0·61	1·81	...
Potash	2·12	6·31	4·71
Soda	0·21	0·63	0·66
Carbonate of lime	49·46	...	...
Peroxide of iron	12·53	...	4·05
Loss	4·43 ‡	...	...
	100·00	100·00	100·00

* It is self-evident that this proportion would be different, if, instead of carbonate of soda, there was carbonate of potash, or a mixture of the two carbonates.

† Poggend. Annal. xlix, 381.

‡ Consisting probably for the most part of water, and perhaps some organic substance.

IX. Composition of the entire mass of the decomposed crystal.

X. Percentage composition after deducting the carbonate of lime and peroxide of iron, which cannot be products of the decomposition of felspar to any sensible amount.

XI. Percentage composition of the portion of the crystals in soluble hydrochloric acid.

It follows from these analyses that X is to be regarded as the residue of the decomposed felspar crystals, this substance corresponds tolerably well with XI in composition.

When dilute hydrochloric acid is poured upon the reddish brown soft crystals of felspar, which still retain the crystalline form, bubbles of carbonic acid are evolved not only from the outer surfaces, but likewise from the interior of the crystals. When the whole of the carbonate of lime has been decomposed, and the greater part of the oxide of iron dissolved, there remains a very porous mass, which, for the most part, presents a skeleton of the original crystal. This appears to be the case with many pseudomorphous crystals that I have examined. It would, however, appear from the greater or less duration of the effervescence that the crystals were in very different stages of decomposition. The liquid which effected the decomposition must, therefore, have penetrated through the entire mass of the felspar.

The following facts will also show that the presence of carbonate of lime and peroxide of iron, which latter was brought in contact with the felspar as bicarbonate of iron, is sufficient to account for the decomposition.

Bicarbonate of lime and silicate of potash yield carbonate of potash, and carbonate of lime, silica being liberated.* It may, therefore, be supposed that water containing bicarbonate of lime has effected the decomposition of the felspar; that half of the carbonic acid had decomposed the alkaline silicates, and that the alkaline carbonates thus formed were removed by water, together with the silica separated in the decomposition, while the carbonate of lime was deposited in their place. If the water that effected the decomposition contained, besides bicarbonate of lime, bicarbonate of iron, a portion of the alumina might have been removed.† Since, moreover, the hydrated peroxide of iron, produced by the oxidation of bicarbonate of iron in the water, would decompose alkaline silicates,‡ forming persilicate of iron,

* English edition, i, 12, No. 11.

† See ante, p. 74, No. 49.

‡ See ante, p. 71, No. 48.

the decomposition of the alkaline silicates in the felspar might have been effected at the same time by the carbonates of lime and of iron.

It may, therefore, be understood that water containing these substances in solution might entirely remove the silica, alkalies, and alumina of felspar. Thus, since the composition of X is very similar to that of felspar, and since this substance amounts to only one-third of the original felspar, there have been two-thirds removed, and carbonate of lime and hydrated peroxide of iron deposited in their place. Since, moreover, in X the proportion of alkalies is less, and that of alumina greater, than that in unaltered felspar, it would appear that this residue was also in a state of decomposition, and that the alkalies were removed sooner than the alumina. This would also be in accordance with the above explanation of the decomposition, which commences with the decomposition of the alkaline silicates by the carbonic acid liberated from the bicarbonate of lime, while, at the same time, the alkalies are removed as carbonates.

Haüy, Freiesleben, Bonnard, and Blum* describe felspar, which they suppose to have been converted into steatite. VII and VIII are the compositions of the felspars supposed by Blum to be pseudomorphs of this kind, and it proves on analysis that the substance is kaolin, and not steatite. This mistake is easily made, on account of the great resemblance of steatite and kaolin in some instances.

Felspar with the form of other minerals.—Besides the pseudomorphous orthoclase already described,† after analcime and laumontite, felspar occurs with the form of calc-spar. Blum‡ describes a specimen of this kind from the Pöhler Stollen, near Eibenstock in Saxony. It consists of large crystals, that are rough and flesh colored at the exterior, and inside consist of a yellowish white or reddish mass of compact felspar, in which there are, here and there, small drusy cavities, containing quartz crystals. Moreover, quartz layers, from a line to two lines thick, alternate with the compact felspar. At some places where the felspar mass is more earthy, the felspar has been removed, so that narrow hollow cavities have been formed. Blum is of opinion that these pseudomorphs have been formed by incrustation and alternate deposition towards the interior, of quartz

* German edition, ii, 304 et seq.

† See ante, pp. 140, and 147.

‡ Die Pseudomorphosen, p. 256, and 2^{ter} Nachtrag, p. 103.

and felspar, the latter being almost always in preponderating amount. Within a crust of from 1 to 2 lines, the felspar occupies the entire space, and has displaced the whole of the calc-spar.

It will be shown in treating of limestone, that this pseudo-morph has a considerable geological importance.

B.—GLASSY FELSPAR; SANIDINE.

According to my experiments, glassy felspar from Drachenfels, lost, when digested with hydrochloric acid, 3·73 per cent of substance. Peroxide of iron was extracted in largest quantity, and besides it, silica, alumina, lime, and magnesia. A crystal, somewhat brown colored by oxide of iron, I; and one tolerably colorless, but containing particles of magnetic iron II, both from Drachenfels, were repeatedly digested with hydrochloric acid, the acid liquid being removed each time, filtered, and the residue washed.

				Quantity of substance extracted.	
				I.	II.
Digested for two hours	....	....		2·06 per cent.	... per cent.
" " "	....	....		1·43 "	2·02 "
" " "	....	....		0·52 "	1·59 "
" four	....	....		0·81 "	0·44 "
" eight, after the powder had	} been eight hours in contact with cold hydrochloric acid			0·76 "	0·97 "
Digested for three hours				0·91 "	0·34 "
" two "	....	....		0·55 "	0·84 "
Total quantity extracted				7·04	6·20

The 2·06 per cent. of substance consisted of 1·07 peroxide of iron, 0·09 silica, 0·2 alumina, with traces of lime, magnesia, and alkalies. In the subsequent extracts, the amount of oxide of iron decreased considerably.*

Occurrence.—In trachyte, phonolite, dolerite, basalt, pitchstone, trachytic lava, and in the masses erupted from volcanoes.

* As the residue was not treated with boiling solution of carbonate of soda after each digestion, the greater part of the silica that was separated remained in the residue; so that the entire quantity of felspar decomposed was greater than it appears in the above table.

Composition.

					I.	II.	III.	IV.	V.
Silica	....	....	....	....	67·48	66·1	68·18	67·90	65·62
Alumina	....	....	....	....	18·75	19·8	18·33	19·25	17·16
Peroxide of iron	....	....	....	....	0·60	...	0·71	1·42	1·67
Lime	....	....	....	....	1·01	...	0·51	...	2·44
Magnesia	....	....	....	....	..	2·0	0·16	0·64	trace
Potash	....	....	....	....	8·11	6·9	7·15	5·35	12·67
Soda	....	....	....	....	4·05	3·7	4·66	4·93	0·44
					100·00	98·5	99·70	99·49	100·00
O. Q.	....	....	....	....	0·332	0·354	0·324	0·337	0·335

I. Glassy felspar crystals from the trachyte of Drachenfels. Berthier.

II. Glassy felspar from Mont d'Or. Berthier.*

III. Glassy felspar from the trachytic conglomerate at Langenberg. G. Bischof.

IV. Glassy felspar from a peculiar rock at the Lesser Rosenau, in the Siebengebirge, in which small white translucent crystals, of glassy felspar, are imbedded in small quantity. They did not give off water either in the water-bath or when ignited, and, consequently, were quite unaltered. G. Bischof.

V. Glassy felspar from the trachytic conglomerate of Lutterbach, in the Siebengebirge. Lasch.†

				VI.	VII.	VIII.	IX.	X.	XI.
Silica	....	....	....	67·42	67·09	66·73	65·84	65·36	65·00
Alumina	....	....	....	15·88	18·88	17·56	17·61	19·41	18·64
Peroxide of iron	....	....	....	2·83	1·25	0·81	0·74	0·43	0·83
Oxide of manganese	....	....	....	..	..	..	..	..	0·13
Lime	....	....	....	2·77	0·35	1·23	0·18	0·55	1·23
Magnesia	....	....	....	0·15	0·03	1·20	0·06	0·87	1·03
Potash	....	....	....	10·52	7·58	8·27	14·39	9·32	9·12
Soda	....	....	....	0·43	4·59	4·10	1·18	4·06	3·49
Loss by ignition	....	....	....	..	0·24	..	..	..	..
				100·00	100·01	99·90	100·00	100·00	99·47
O. Q.	....	....	....	0·315	0·337	0·338	0·329	0·362	0·373

* Annales des Mines. 2 Sér. iii and vii.

† Verhandlungen des naturhistorischen Vereins der Rheinlande und Westphalens. ix, 336.

VI. Glassy felspar from the trachytic conglomerate of Scharfenberg. Lasch.*

VII. Glassy felspar crystals from the lava at St. Vico, between Lacco and Forio, in Ischia. G. Bischof.

VIII. Glassy felspar from the rocks of the Epomeo, in Ischia. Abich.†

IX. Large pure crystals of glassy felspar from the volcanic sand—felspathic conglomerate—of Rockeskyll in the Eifel. Bothe.‡

X. Glassy felspar crystals from the decomposed phonolite of Kostenblatt in Bohemia. Heffter and Joy.§

XI. Very pure carefully selected crystals of glassy felspar from the lava of Arso in Ischia. Abich.||

With the exception of II, X, and XI, the oxygen quotients of these minerals is so near 0.333, that there is every reason for taking this as the value of the normal oxygen quotient. In II and X the oxygen quotient is much greater, so that silica has been removed from these minerals. This, however, is the commencement of decomposition into kaolin, and corresponds with that so frequently presented by orthoclase.¶

In the above analyses potash always predominates over soda; it is, therefore, very probable that this is generally the case, and that two analyses, not included in the table, which show a contrary relation of these bases are either exceptions or erroneous.

Formation.—The glassy felspar crystals III, V, and VII, from the trachytic conglomerate, are remarkably fresh and unaltered. Their edges and corners are quite sharp, and their numerous faces perfectly smooth and brilliant.** Now since the trachytic conglomerate is very evidently stratified, since it presents in many places impressions of leaves, and contains fossil-wood, its sedimentary origin cannot be questioned. Then, if these felspar crystals existed in the trachytic rock from which the conglomerate originated by mechanical and chemical disintegration, they would, like the other ingredients of this rock, have been removed by the action of water and like the more or less altered fragments of trachyte, and rounded masses of grauwacke, which occur at some

* Verhandlungen des naturhistorischen Vereins der Rheinlande und Westphalens, ix, 336.

† Geolog. Beobachtungen neber die vulkanischen Erscheinungen und Bildungen in Unter-und Mittel-Italien, 1841, p. 7.

‡ Verhandlungen, &c. p. 336.

§ Miscell. Chem. researches. Göttingen, 1853, p. 30.

|| Loc. cit. p. 44.

¶ See ante, p. 176.

** v. Dechen—Verhandlungen, &c., loc cit. p. 458.

places in the conglomerate, would have been altered and removed. But their remarkably fresh and unaltered condition is wholly inconsistent with such a supposition, so that they must have been formed in the conglomerate, and that can have taken place only in the wet way.

If it were assumed that the conglomerate was formed from trachyte that was decomposed on the spot, the perfect state of the felspar crystals would be inconsistent with this view; for it is difficult to imagine that the principal mass of this rock could undergo the considerable alteration which it presents, while the crystals contained in it escaped this alteration altogether. The oxygen quotients of X, which, next to that of XI, is the highest of all the specimens of glassy felspar yet analyzed, show that crystals of this mineral, from decomposed rocks, may likewise be somewhat altered, although they still retain the sharpness of their edges and corners, and their transparency. But the normal oxygen quotient of the felspar crystals III, V, and VI, from the conglomerate, shows that they are not altered either chemically or mechanically.

The occurrence of glassy felspar crystals VII and VIII, in lava, is regarded by Plutonists as an incontrovertible proof that they were formed by fusion; but it is only in the older lava that these felspar crystals occur, and the inference that may be drawn from this fact has already been pointed out.* The trachytic lava that flowed from Arso in the year 1301, from which the felspar crystals XI are obtained, is the only known product of eruption in Ischia within the historic period.† The eruption of the lava at St. Vico, in Ischia, from which the felspar crystals VII are obtained, was prior to this period. If the glassy felspar crystals in the trachytic conglomerate of the Siebengebirge are formed in the wet way as, I believe I have proved to be the case, the same view must be taken of the origin of the felspars VII and XI, for the principal mass of the lava, in which the latter occur, contains the material requisite for their formation, as well as the conglomerate. With regard to the formation of the felspar crystals in the lava of Arso, there is a period of 500 years; but this period comprises not only their formation, but also their partial decomposition, for the oxygen quotient of XI is the highest of all the specimens of glassy felspar that have yet been analyzed, and this shows that there has been a loss of about 3 per cent. of silica.

I must leave it to the judgment of my readers to appreciate the arguments which I have brought forward to prove the

* See ante, p. 95.

† Abich. loc. cit. p. 42.

formation of glassy felspar occurring in trachytic conglomerate and trachytic lava in the wet way, and to consider whether there are any grounds for supposing that the crystals of this mineral occurring in trachyte and trachytic dykes have been formed in any other way.

We have no knowledge of any alteration to which glassy felspar is subject, although the great similarity of its composition to that of orthoclase, would admit of the inference that it undergoes alterations analogous to those of the latter mineral. However, glassy felspar appears to be produced by the alteration of leucite and if by chemical analysis this should be proved to be the case, there would be another argument in favour of its formation in the wet way.

C.—RYAKOLITE.

This mineral is powerfully acted upon by acids.

Occurrence.—In lava and other volcanic products at Vesuvius, and at the Lake of Laach, partly in crystals in the rocks, partly in drusy cavities. It was distinguished from glassy felspar by G. Rose.*

Composition.—According to G. Rose:

Silica	....	....	50·31
Alumina	....	....	29·44
Peroxide of iron	....		0·28
Lime	....	....	1·07
Magnesia	....	....	0·23
Potash	....	....	5·92
Soda....	....	....	10·56
			— —
			97·81
O. Q.	....		0·666

D.—ALBITE.

This mineral is not acted upon by acids.

Occurrence and formation.—Sometimes in granite; generally in diorite and dioritic porphyry, particularly in drusy cavities and fissures of these two rocks, as well as in hornblende-slate, granite, and gneiss. The remarkable occurrence of albite crystals upon orthoclase has already been spoken of. Albite also occurs in small cavities in syenite, according to Weibye.† Sandberger states,‡ that it occurs in drusy cavities in the Tannus slate. The fissures everywhere present in these rocks are filled with quartz and almost always contain crystals and crystalline masses of albite. It also

* Poggendorff's Annalen. xv, 193, and xxviii, 143.

† Archiv. für Mineral. etc. xxii, 528.

‡ Jahrbücher des Vereins für Naturkunde in Herzogthum Nassau, vi, 4.

occurs in large granular masses imbedded in the quartzose slate of Wurzburg and Leichtweisshöhle, with imbedded microscopic crystals of magnetic iron and micaceous iron. A specimen of Tannus slate, from the neighbourhood of Homburg which I procured from v. Dechen, likewise contains, on the surface of a fissure, small crystals of felspar, probably albite mixed with some quartz and micaceous iron. Scharff* also found fine crystals of albite mixed with chlorite quartz and felspar in a dyke-like cavity in the green Tannus slate at the Königstein Burgberg.

Albite occurs in Sweden, at Finbo and Brodbo, near Fahlun, on quartz dykes in gneiss. Weibye† found in the island of Langö, Norway, albite crystals which intersected calc-spar in all directions. It also occurs in cavities in compact albite.‡

In the Berlin collection of minerals I saw a specimen from Arendal, in which albite was situated upon epidote, was imbedded in it in small particles, and also filled up rents in the latter mineral.

All these facts show decisively that the formation of albite has taken place in the wet way, and that very recently, inasmuch as it is posterior to calc-spar and epidote.

Composition.—The earlier analyses, which do not indicate the presence of potash, are omitted. Among the more recent analyses there are two § which do not indicate potash in the minerals they represent, but albite of this kind is rare.

I. Pericline, from Zöblitz, in the Erzgebirge	} Analyzed by C. Gmelin ||	O. Q. 0·339
II. Crystallized albite from green-stones at Miask	} Abich ¶	.... 0·338
III. Albite from Brevig in Norway	Erdmann **	.... 0·338
IV. Pericline from the trachyte in Pantellaria	} Abich ††	.... 0·335
V. Crystallized albite, with crystallized felspar, from druses in the granite of the Riesengebirges, near Schreiberschau	} Lohmeyer ††	.... 0·340

* Jahrbücher des Vereins für Naturkunde in Herz. Nassau, ix, 41.

† Loc. cit. xxii, 507.

‡ Ibid. p. 469.

§ See ante, pp. 194, 167, xiii and xviii.

|| Kastner's Archiv. ii, 92,

¶ Berg und Hüttenmannische Zeitung, i, No. 19.

** Berzelius Jahresbericht, xxi, 192.

†† Poggend. Annal. li, 526.

‡‡ Ibid. lxi, 390.

	Analyzed by	O. Q.
VI. Albite from the deep Fürstentollen, near Freiberg	Kersten*	.... 0.331
VII. Albite from a rock resembling micaceous schist, and containing garnet, at Marienbad, Bohemia	Kersten†	.... 0.327
VIII. Albite crystals of great purity from Snarum in Norway. They are snow-white, very translucent, and have a pearly lustre at the surfaces of cleavage. This mineral contains more lime than any other specimen of albite	Scheidthauer‡	0.364
IX. Albite from phonolite rock at in Laugafjall, Iceland	Damour§	.... 0.354
X. Snow-white, fine grained albite, from St. Gotthard	Brooks||	.... 0.346
XI. Mineral resembling albite, from Pennsylvania. It is snow-white, translucent at the edges, and has the hardness of albite	Redtenbacher¶	0.358
XII. Mineral resembling albite, from Pisoje, near Popayan, in Columbia. Its general appearance is like that of albite. The crystals are snow-white, translucent, and lustrous at the surfaces of cleavage, but not sufficiently even to admit of the re-entering angles being measured	Francis**	.... 0.575

* Journ. für prakt. Chemie. xxxvii, 172.

† Jahrbuch für Mineral. &c. 1845, p. 648.

‡ Poggend. Annal. lxi, 393.

§ Bull. de la Soc. Géol. Sér. 2. vii, 83.

|| Poggend. Annal. lxi, 392.—See ante, p. 167, No. x.

¶ Ibid. lii, 468.

** Ibid. p. 471.—See p. 199, oligoclase, xxxiv.

	Analyzed by	O. Q.
XIII. Granular white albite from Lancaster in Pennsylvania	Brush*	.... 0·372
XIV. A similar mineral from Unionville, Chester, Pennsylvania	Weld†	.... 0·381
XV. A similar mineral from Westchester	Boyé and Booth‡	0·361
XVI. The same from Wilmington, Pennsylvania; very liable to disintegration	Boyé and Booth‡	0·388
XVII. Albite from Canada; the peristerite of Thomson	Hunt§	.... 0·378

The oxygen quotients of the specimens of albite, from I to VII inclusive, approximate so closely to 0·333, that this may be taken as the normal value. The oxygen quotients of the other specimens, however, exceed this value, and this shows that there has been a removal of some silica. Hence it would follow that this kind of gradual decomposition is common to all of them, that is to say, that they are in a state of transition into kaolin.

It is remarkable that the specimen VIII, although presenting all the exterior indications of perfect integrity, is somewhat decomposed. Perhaps it is only the transparent albite that is perfectly unaltered, while that which is only translucent is already in a state of incipient decomposition. In future analyses of albite, particular attention should be paid to these external characters, so that by comparison with the results of analyses, the value of this conjecture may be determined.

The high oxygen quotient of XII indicates a far advanced decomposition or conversion into kaolin, and is quite inconsistent with the external characters, which would appear to indicate the contrary. Perhaps the mineral is a slightly altered labrador. The large percentage of lime, and the general composition of the mineral would favour this view.

The high oxygen quotients of the specimens XIII to XVII inclusive, are quite inconsistent with the statement that the albite XIII and XIV were harder than the quartz; for at the commencement of conversion into kaolin the hardness must decrease. This point requires further examination.

* Silliman's Journ. Ser. 2, viii, 300.

† Ibid.

‡ Proceedings of the American Philos. Soc. ii, 190.

§ Phil. Mag. Ser. 4, i, 322.

Percentage composition of normal and altered albite selected from the above.

	VII.	IV.	I.	VIII.	XVI.	XII.
Silica	68.70	68.23	67.94	66.11	65.46	56.72
Alumina	17.92	18.30	18.93	18.96	20.74	26.52
Peroxide of iron	0.72	1.01	0.48	0.34	0.54	0.70
Lime....	0.24	1.26	0.15	3.72	0.71	9.88
Magnesia ....	...	0.51	...	0.16	0.74	...
Soda	11.01	7.99	9.99	9.24	9.98	6.19
Potash	1.8	2.53	2.41	0.57	1.80	0.80
Loss by ignition ....	...	...	0.36	...	...	...
	99.77	99.83	100.26	99.10	99.97	100.31
O. Q.	0.327	0.335	0.339	0.364	0.388	0.575

Conversion into kaolin.—The great tendency of albite to be converted into kaolin is undoubtedly connected with the preponderance of soda in its composition, as is evident from the above analyses. The total conversion into kaolin is presented, among other places, in the Erzgebirge in a rock resembling greenstone,* and in a moor near Marienbad, where masses of albite are converted into a substance resembling kaolin, probably by the action of carbonic acid exhalations, while, at the same place, orthoclase is not the least altered.

Wernerite appears to be convertible into albite,† but perhaps this albite is only a product of infiltration.

Morlot‡ speaks of pseudomorphous orthoclase with the form of albite.

E.—OLIGOCLASE. SODA-SPODUMENE.

Schmid found that this felspar does not altogether resist the action of acids, for when digested with hydrochloric acid for some weeks at a temperature of about 144° F., 5.16 per cent. of substance was extracted.

Occurrence.—In granite, gneiss, augitic porphyry, trachyte, hornblende rock, &c. The specimens referred to below, are from several other rocks.

Composition.—I have given all the analyses that have been made, except one in which the alkalis were not estimated separately. The soda always predominates over potash; but the latter base is rarely absent, perhaps never.

* Naumann.—Erläuterungen, ii, 219 et seq.

† See Chapter xxix.

‡ Jahrbuch für Mineral. etc. 1847, p. 845.—A more detailed account of this pseudomorph is desirable, as such an alteration, if proved, would be very interesting.

	Analyzed by	O. Q.
I. Greenish-white oligoclase, from the kersantite, micaceous diorite of Visembach in the Vosges	Delesse*	.... 0.405
II. Yellowish-grey or yellowish-white to pea-green oligoclase, (Breithaupt) from Hammond, New York; associated with augite, graphite, and calcspar; situated upon the two former minerals, and covered by the latter	Plattner†	.... 0.405
III. Reddish oligoclase from the tantalite quarry in the granite at Kimito, in Finland. This mineral differs from most varieties of oligoclase by the total absence of magnesia; it does not contain any oxide of iron, which, from its red colour, is remarkable	Chodnew‡	.... 0.407
IV. Greenish-white oligoclase, from the dark green porphyry at Quenast in Belgium	Delesse§	.... 0.412
V. Oligoclase from the masses ejected from the Peak of Teneriffe	Deville||	.... 0.415
VI. Yellowish-white oligoclase, from a granite boulder in Schleswig Holstein	Wolff¶	.... 0.416
VII. Greenish-white to leek-green oligoclase, from coarse grained granite forming a dyke in serpentine at Schaitansk, in the Ural	Bodemann**	.... 0.418

* Annal. des Mines. Sér. 4, xix, 165.

† Poggend. Annal. lxvii, 419.

‡ Ibid. lxi, 390.

§ Annal. des Mines. Sér. 4, xviii, 103.

|| Etudes géologiques sur les Isles de Teneriffe et de Fogo. Paris, 1848.

¶ Journ. für prakt. Chemie. xxxiv, 234.

** Poggend. Annalen. Iv, 110.

	Analyzed by	O, Q.
VIII. Snow-white, yellowish, or greenish oligoclase, from the granite of Warmbrunn, in Silesia	Rammelsberg*	0.425
IX. Crystallized oligoclase from Arendal	Hagen†	.... 0.428
X. Oligoclase from the volcanic rocks in Teneriffe	Delesse‡	.... 0.428
XI. Greenish oligoclase from the gneiss of the deep Fürstentollen, near Freiberg	Kersten§	.... 0.430
XII. Oligoclase from glassy lava at the Peak of Teneriffe	Deville||	.... 0.432
XIII. Oligoclase from the trachyte of the gorge of Fuente Agria	Deville||	.... 0.432
XIV. Oligoclase from the granite of Elba	Damour¶	.... 0.433
XV. Pale yellowish-green massive oligoclase from a granite dyke near Danviks-Zoll, Sweden	Berzelius**	.... 0.436
XVI. Blueish-green or yellowish oligoclase from hornblende rock on the summit of the Hamelika, near Marienbad, Bohemia	Kersten††	.... 0.436
XVII. White and green oligoclase from the protogyn of the Alps	Delesse‡‡	.... 0.437
XVIII. Calcareous oligoclase, hafnefjordite, from cavities in the lava of Hafnefjord, Iceland	Forchhammer §§	0.444
XIX. Leek-green oligoclase, from Boden, in the Erzgebirge	Kerndt |||	.... 0.445
XX. Oligoclase from Arriege in France	Laurent ¶¶	.... 0.449

* Poggendorff's Annalen. lvi, 617.

† Ibid. xliv, 329.

‡ Comptes rendus, xix, 46.

§ Journ. für prakt. Chemie. xxxvii, 173.

|| Etudes, etc.

¶ Rammelsberg, Supplement 5, 178.

** Jahresbericht, iv, 147.

†† Jahrbuch für Mineral. etc. 1845, 653.

‡‡ Annal. de Chimie. et de Phys. Sér. 3, xxv, 14.

§§ Journ. für prakt. Chemie. xxx, 389.

||| Ibid. xliii, 214.

¶¶ Annal. de Chim. et de Phys. lix, 108

	Analyzed by	O. Q.
XXI. Oligoclase crystals from the augitic porphyry of Ajatskaja, in the Ural	Francis*	.... 0·451
XXII. Oligoclase crystals from Arendal	Rosales†	.... 0·453
XXIII. Oligoclase from Ytterby	Berzelius‡	.... 0·464
XXIV. Calcareous oligoclase from Sala, near Mellandamsbacken	Svanberg§	.... 0·470
XXV. White and red oligoclase, aventurine, from the gneiss dykes near Foedesstrand, Norway. The remarkable play of colour in this mineral is probably owing to the presence of imbedded crystals of specular iron. However, the oxide of iron extracted by hydrochloric acid amounted to only $\frac{1}{3}$ or $\frac{1}{4}$ per cent. It would appear that the oligoclase and specular iron were formed together. Besides the crystals at the exterior, there were in the interior several irregular shaped masses of the same substance as the crystals. The remarkable shapes of these masses would appear to indicate, that they resulted either from disturbed crystallization, or from the partial destruction of crystals. The length of the longest crystals were 0·308 line; some were only 0·12 line. The thickness of the reddish crystals was 0·00035 and 0·00017, that of the yellow crystals only about 0·00001 line	Th. Scheerer ||	0·470 ¶

* Poggend. Annal. lii, 470.

† Ibid. lv, 470.

‡ Berzelius's Jahresbericht, xix, 302.

§ Ibid. 248.

|| Poggend. Annal. lxiv, 153.

¶ This high oxygen quotient would appear to indicate that the substance analyzed, contained particles that had been converted into kaolin.

	Analyzed by	O. Q.
XXVI. Milk-white oligoclase crystals from the diabase of Chalanges near Allemont	Lory *	.... 0.483
XXVII. Oligoclase from a similar rock at Bourg d'Oisans	Lory †	.... 0.487
XXVIII. Reddish oligoclase from red antique porphyry	Delesse ‡	.... 0.493
XXIX. Andesine, from the dioritic porphyry—andesite—of Mar- mato. It approximates in point of fusibility to oligo- clase	Abich §	.... 0.500
XXX. The same mineral	Rammelsberg ||	0.504
XXXI. Milk-white oligoclase from the syenite of Ballon de Servance, Vosges	Delesse ¶	.... 0.502
XXXII. Coral-red oligoclase from the syenite of Coravillers, Vos- ges	Delesse ¶	.... 0.505
XXXIII. Oligoclase, in greyish-green granules, from the variolite of the Durance; Mont Genèvre near Briançon	Delesse **	.... 0.529
XXXIV. Felspar from the porphyry, granito amandola, of the Esterrel, near Fréjus, in the south of France	Rammelsberg ††	0.544

Rammelsberg remarks that this felspar as well as andesine, may be regarded as a compound of 1 atom oligoclase with 2 atoms of labrador, and he points out the close resemblance between these minerals and the albite felspar from Pisoje. ††

* Bullet. géol. de France. Sér. 2, vii, 542.

† Ibid.

‡ Annal. de Chim. et Phys. Sér. 3, xxx, 81.

§ Poggend. Annal. li, 523.

|| Supplement 4, p. 47.

¶ Extract des Mémoires de la Société d'Emulation du Doubs.

** Annal. des Mines. Sér. 4, xvii, 119.

†† Loc. cit.

‡‡ See ante—albite, p. 193, No. xii.

	Analyzed by	O. Q.
XXXV. Snow-white felspar associated with hornblende, from a coarse grained rock of which it constitutes the principal portion	Varentrapp*	.... 0.534

This felspar, which may be regarded as analogous to labrador, resembles in regard to composition and oxygen quotient, the minerals XXXIII and XXXIV. This cannot be decided mineralogically, because it does not occur in crystals.

XXXVI. Greenish felspar crystals from the porphyry of Chagey, Haute Saone	Delesse† 0.482
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Delesse regards this mineral as andesine; but I believe it to be oligoclase somewhat decomposed, especially since it contains 2.28 per cent. water, and carbonate of lime besides. These crystals become brick red at first, when exposed to the action of the atmosphere, and are then converted into kaolin.

Delesse regards both the felspars, XXXI and XXXII as identical with andesine. G. Rose‡ objects to this that the individuality of this mineral, that has been analyzed only once, is by no means proved; and he is of opinion that these specimens are oligoclase, somewhat decomposed. This is borne out by the percentage of water. Delesse himself remarks that these felspars are rarely unaltered, but are generally milk-white or coral red, and sometimes pass into kaolin. I am, therefore, inclined to adopt Rose's opinion, with the further opinion that andesine is merely a somewhat decomposed oligoclase. In fact the oxygen quotients of XXXI and XXXII agree almost completely with those of XXIX and XXX, and the analytical results show the same correspondence. With regard to XXXIV it might be conjectured that it is likewise oligoclase, but that it is in a more advanced stage of decomposition than any of the other specimens, although this would not be very consistent with its occurrence in fine large crystals.

The mean value of the oxygen quotients of the specimens of oligoclase, VIII to XXII inclusive, which differ but little from each other, is 0.438. This is so near 0.444, that of the formula assigned to oligoclase, that it may be taken as the normal value.

* Poggend. Annal. lii, 473.

† Loc. cit.

‡ Zeitschrift der deutschen geolog. Gesellschaft, i, 369—German edition, ii, 919 et seq

The oxygen quotients of the minerals I to VII inclusive are lower, and those of the minerals XXIII to XXXV inclusive, are higher than this; in the latter, considerably so. The decomposition by loss of silica, and the tendency to the formation of kaolin appears, therefore, to predominate. On the other hand, it is possible that the lime which is present in all specimens of oligoclase, and sometimes amounts to 8·22 per cent., is the condition which determines the reduction of the oxygen quotient, inasmuch as the silicate of lime is specially liable to decomposition. But if carbonic acid is the decomposing agent, there would be a loss of bases, and consequently a reduction of the oxygen quotient. It is actually the case, that the smallest quantity of lime—1·10 to 4·12 per cent.—is met with in those kinds of oligoclase which have a low oxygen quotient, and the larger quantities—2·81 to 8·74 per cent.—in those which have high oxygen quotients. Water has never been found in any oligoclase that has a normal oxygen quotient, but, on the contrary, among the specimens with low oxygen quotients, I, II, and III, contain water, while among those with high oxygen quotients, XXVI, XXVII, XXVIII, XXIX, and XXXIV, likewise contain water. The quantity of water varies from 0·6 to 2·3 per cent.* It is worthy of notice that the andesine specimens, with the exception of XXXIV are not hydrated, and this is certainly opposed to the opinion that they are decomposed oligoclase.

Percentage composition of normal and altered oligoclase selected from the previous analyses.

	I.	XIII.	XVIII.	XXV.	XXX.	XXXIV.
Silica	63·88	61·55	61·22	61·30	60·26	58·32
Alumina	22·27	22·03	23·32	23·77	25·01	26·52
Peroxide of iron	0·51	....	2·40	0·36	trace	....
Lime	3·45	2·81	8·82	4·78	6·87	8·18
Magnesia ....	....	0·47	0·36	....	0·14	0·11
Soda	6·66	7·74	2·56	8·50	7·74	5·27
Potash	1·21	3·44	trace	1·29	0·84	2·36
Loss by ignition....	0·70	....	....	....	....	0·60
	98·68	98·04	98·68	100·00	100·86	101·36
O. Q.	0·405	0·432	0·444	0·470	0·504	0·544

Formation.—The evidence of the formation of oligoclase in the wet way is not so decisive as in the case of feldspars already treated

* The oligoclase from the euphotide of Lavalens, Depart. Isère, contains, according to Delesse, 2·3 per cent.

of especially since this mineral, so far as is known, does not occur in drusy cavities. However, the occurrence of the oligoclase XVII in veins of gneiss, and the presence of the small crystals of specular iron imbedded in it, exclude the possibility of a plutonic origin.

Conversion of oligoclase into kaolin.—The specimens XX to XXXV inclusive, whose oxygen quotients are above the normal value, present a more or less advanced conversion into kaolin, and the total conversion has already been alluded to.

F. SPODUMENE, TRIPHANE.

This mineral is not much acted upon by acids, either before or after ignition.

Occurrence.—In beds of magnetic iron ore in gneiss, at the Island of Utö, and in the granite of several places in the Tyrol, Scotland, North America.

Composition.—The analyses by Vauquelin and Vogel, which were made prior to the discovery of lithium in spodumene, can have no value.

					I.	II.	III.	IV.	V.
Silica	....	....	....	....	66·40	63·29	65·30	65·25	66·03
Alumina	....	....	....	....	25·30	28·78	25·34	} 27·56	26·45
Peroxide of iron	....	....	....	....	1·45	0·79	2·83		
Oxide of manganese	....	....	....	....	....	0·20	....	
Lithia	....	....	....	....	7·98	5·07	6·09		
Soda	....	....	....	....	0·67	0·43	0·51		
Potash	....	....	....	....	0·20	0·13	0·16		
Loss by ignition	....	....	....	....	0·45	0·78	....	
					102·45	99·47	100·23		
O. Q.	....	....	....	....	0·488	0·506	0·447		

					VI.	VII.	VIII.	IX.	X.	XI.
Silica	....	....	....	....	65·02	65·02	65·53	62·89	62·76	65·27
Alumina	....	....	....	....	26·84	29·14	29·04	28·42	29·33	27·47
Protoxide of iron	....	....	....	....	0·86	trace	1·42	....	....	....
Lime	....	....	....	....	....	0·50	0·97	1·04	0·63	0·30
Magnesia	....	....	....	....	....	0·14	0·07	....	....	0·10
Lithia	....	....	....	....	3·84	5·47	4·49	5·67	6·48	2·90
Soda	....	....	....	....	2·68	0·46	0·07	2·51	1·76	0·44
Potash	....	....	....	....	....	0·14	0·07	....	....	4·54
					99·24	100·87	101·66	100·53	100·96	101·02
O. Q.	....	....	....	....	0·459	0·502	0·490	0·530	0·459	0·455

I. Spodumene from Utö	Analyzed by Arfwedson.*
II. The same mineral	Stromeyer.†
III. The same mineral containing 6·76 per cent. lithia	Regnault.‡
IV. Spodumene from Sterling, Massachusetts	Hagen.§
V. Spodumene from Sterzing, in the Tyrol	Hagen.§
VI. Spodumene from Utö, corrected by Rammelsberg in accordance with VII.	Hagen.§
VII. Spodumene from Utö	Rammelsberg.||
VIII. Spodumene from the Tyrol	
IX. Spodumene from Norwich	
X. Spodumene from Sterling	Brush.¶

The alkalies were not estimated directly in any of these analyses except VII, VIII, and IX.

XI. Spodumene from Sterling Rammelsberg.**

Each of the three analyses by Rammelsberg is the mean of three.

Since the alkalies were estimated directly only in VII, VIII, and IX, the normal oxygen quotient can be estimated only from them. According to VII and VIII, it is very nearly 0·5, and this corresponds tolerably well with the oxygen quotient in II. This analysis has indeed been corrected subsequently, but Stromeyer estimated the sulphuric acid of the alkaline sulphates obtained, so that the quantity of the alkalies was found directly. It should not be overlooked that the somewhat considerable loss by ignition in II, would indicate that alteration had already commenced. Arfwedson calculated the quantity of alkali from that of the sulphate obtained upon the assumption that it was pure sulphate of lithia, and thus obtained an inaccurate result. Since, moreover, his analysis indicates a much greater amount of alkali than any others, and since there is considerable surplus, there can be

* Schweigger's Journ. xxii, 107.

† Untersuchungen über die Mischungen der Mineralkörper, i, 426.

‡ Annal. des Mines. Sér. 3, 380.

§ Poggend. Annal. xlviii, 369.

|| Handwörterbuch, etc. Supplement 5, p. 227.

¶ Loc. cit.

** Loc. cit.

little doubt that the oxygen quotient is too high.* Consequently the oxygen quotients of I, VI, XI, and probably also that of III, are below, while those of IX and X are above the normal value. Hence it follows that these former minerals have lost some of their silica, and that the latter are being converted into kaolin.

Spodumene with the form of augite.—Blum † describes crystalline masses with laminated texture and the form of augite, but without stating their source.

G.—PETALITE.

This mineral is not acted upon by acids either before or after ignition, but it is partially decomposed by boiling acid.

Occurrence.—In beds of magnetic iron ore in the gneiss of Utö, of the tin-ore mine of Nya-Kopparberget, and at Sala in Sweden; in the granular limestone of Bolton and Littleton in Massachusetts, and in the boulders at lake Ontario in North America.

Composition.

					I.	II.	III.	IV.
Silica	....	....	....	....	79.12	79.12	74.17	74.17
Alumina	....	....	....	....	17.23	17.23	17.41	17.41
Lithia	....	....	....	....	5.76	3.11	} 5.16	2.78
Soda	....	....	....	....	...	2.65		2.38
Lime	....	....	....	....	...	...	0.39	0.32
Loss by ignition	....	....	....	....	...	...	2.17	2.17
					102.11	102.11	99.23	99.23
O. Q.					0.272	0.253	0.287	0.266

					V.	VI.	VII.	VIII.
Silica	....	....	....	....	77.81	77.07	77.79	78.01
Alumina	....	....	....	....	17.20	18.00	18.58	18.86
Peroxide of iron	....	....	....	....	...	...	...	...
Lithia	....	....	....	....	2.69	2.66	3.30	0.61
Soda	....	....	....	....	2.30	2.27	1.19	2.76
					100.00	100.00	100.86	100.24
O. Q.					0.250	0.261	0.267	0.259

* Arfwedson remarks that he is unable to account for the surplus obtained not only in the analysis of spodumene, but also in that of petalite. This is partly owing to the fact that he estimated the sulphuric acid in sulphate of lithia too low.

† Lehrbuch der Oryktognosie. Ed. 3, p. 285.

		Analyzed by
I. Uncrystallized petalite from Utö.	}	Arfwedson.*
Lithia was first discovered in this mineral		
II. The same analysis, calculated upon the assumption that the mineral contained both soda and lithia in the same proportions as V and VI	}	
III. Petalite		C. G. Gmelin.†
IV. The same calculated as II.		
V. & VI. Petalite		Hagen.‡
VII. Pale reddish petalite from Utö mean of two analyses	}	Rammelsberg.§
VIII. Castor, a mineral described by Breithaupt as occurring in the druses of granite in Elba, mean of three analyses	}	Plattner.||

According to G. Rose, castor agrees with petalite in cleavage, and differs from it only in external appearance, and somewhat lower specific gravity.

Petalite is one of those minerals that contain the largest amount of silica. The oxygen quotients of I and III are evidently too high, because in these analyses the lithia was not separated from soda.¶ The oxygen quotients of II and III, are, therefore, nearer the true value, and likewise agree tolerably well with the rest. There would be little error in taking 0.25 as the normal value of the oxygen quotient. The considerable loss by ignition in III and IV admits of the supposition that alteration had commenced. This likewise agrees with the higher oxygen quotient and the fact that Gmelin found 77.5 per cent. silica, in another specimen of petalite that would consequently appear to be unaltered or less altered than III or IV.

The specimen of petalite VII, has certainly as high an oxygen quotient as IV, although like the other specimens it is anhydrous. If 0.25 is the normal value of the oxygen quotient it may be inferred that IV, VI and VII, have already lost some silica, and that their conversion into kaolin has already commenced. The oxygen quotient of the castor is very near to the normal value, but the deficiency of soda is not replaced by lithia which does not amount

* Schweigger's Journ. xxii, 93.

† Gilbert's Annal. lxii, 399.

‡ Poggend. Annal. xlviii, 361.

§ Ibid. lxxxv, 552.

|| Ibid. lxix, 436 and 443; lxx, 162; lxxxv, 544.

¶ Compare note, p. 204.

to more than in the other specimens of petalite; on the contrary it contains the largest quantity of alumina.

I.—LABRADOR.

This mineral is either wholly or partially decomposed by acids both before and after ignition; sometimes the silica is separated as powder, and sometimes as a gelatinous mass. The more the mineral is altered the more readily is it decomposed by acids.

Occurrence.—Labrador appears to be the felspathic ingredient of most augitic rocks—basalt, dolerite, melaphyr, hyperite, greenstone, diabase, euphotide, amygdaloid porphyry, diorite, trachytic dolerite, etc., and of augitic lava. It likewise occurs in some hornblende rocks.

Composition.—The essential constituents of labrador are silica, alumina, lime, and soda; perhaps also potash, as its presence is almost always indicated in the more recent analyses. Iron is rarely absent; manganese and magnesia are less frequent. The following analyses of hydrated and anhydrous labrador show that the amount of alkalies increases as that of lime decreases, and the reverse.

	I.	II.	III.	IV.	V.
Silica	53.42	52.52	52.17	54.25	55.23
Alumina	29.71	30.03	29.22	29.89	24.24
Peroxide of iron....	....	1.72	1.90	....	1.11
Lime	12.35	12.58	13.11	11.12	6.86
Magnesia ....	....	0.19	....	0.70	1.48
Soda	4.52	{ 4.51	3.40	3.63	4.83
Potash					
Water ....	....	....	....	....	3.05
	100.00	101.55	99.80	99.92	99.83
O. Q.	0.667	0.709	0.694	0.652	0.555

- I. Theoretical composition

II. Labrador from the doleritic porphyry
of the Faroe Islands

III. Yellowish labrador from a trap rock
at Diupavag, in Iceland

IV. Labrador from the trachytic dolerite
of the central peak of Guadeloupe
- Analyzed by

Forchhammer.*

Damour.†

Deville.‡

* Journ. für prakt. Chemie. xxx, 387.
† Bullet. géol. Sér. 2, vii, 88.
‡ Ibid. viii, 426.

V. Labrador from the euphotide of } Analyzed by
 Odern, Alsace } Delesse.*

The oxygen quotients of the specimens III and IV of labrador, approximate tolerably to the normal value, but that of the hydrated labrador V, already more or less altered and effervescing with acids deviates considerably from it.

Formation.—The occurrence of labrador in lava, would appear to indicate that it has been formed by fusion, but since the specimens XIV and XV occur in old lava, while the labrador crystals found in sand at Etna, indicate the perfect decomposition of the lava and consequently a very remote antiquity, this circumstance cannot in accordance with previous remarks† be considered as evidence of such a mode of formation. Since, however, the Etna lava of 1852 is crystalline, and consists of labrador and augite, there can be no doubt of the crystalline separation of the two minerals. The large mass of lava erupted from Etna in 1669 likewise contains small crystals of labrador.

In a schalstein from the district of Brilon, v. Dechen‡ found the impression of a *cyathophyllum* similar to those occurring frequently in the adjoining clay slate. Hence, it is evident that the two rocks have originated in the same way. On the other hand, distinct large crystals of labrador together with small granular masses of limestone, or between patches of black clay slate, indicate the connection of the schalstein with schalstein porphyry, and with the labrador rocks.

Unless schalstein and clay slate, are supposed to be rocks that have undergone plutonic metamorphism, the formation of these labrador crystals in the wet way cannot be doubted.

Alteration.—The conversion of labrador into pinite is the only one yet known, and it will be treated of in chapter xxxii.

Decomposition.—Labrador is distinguished from other kinds of felspar, by its liability to decomposition, which is undoubtedly owing to the amount of lime it contains. In the neighbourhood of Dillenburg greenstone occurs with small crystals of labrador, which are quite fresh at some places, while at others they are more or less disintegrated. I found that the unaltered crystals are seldom quite white, but generally greenish, though not uniformly; and microscopic, dark green specks and veins are distributed in various directions and between the planes of cleavage.§ The dis-

* Ann. des Mines. Sér. 4, xvi, 324.

† See ante. p. 95.

‡ Archiv. für Mineral. etc. xix, 518.

§ German edition, ii, 1077 et seq.

integrated crystals are yellowish-brown, opaque, and very soft when the disintegration is complete; the specks and veins in these crystals are ochre coloured. These specks and veins could not be separated from the mass of the crystals, but such as contained the fewest were selected for analysis. For this reason the quantity of material was very small and the analysis could not be made with sufficient accuracy. The alkalies could not be estimated directly. However, by the comparison of the results obtained by the analysis of the unaltered and disintegrated crystals, it was possible to ascertain the nature of the decomposition. It was evident that the entire mass of the rock as well as the crystals contained carbonate of lime, for both effervesced with acids.

The labrador was dried at 212° F., and gave off more water the more disintegrated the specimens were. The carbonates were extracted by dilute hydrochloric acid, and the residue decomposed by carbonate of potash. The deficiency in the analyses represents the difference between the diminution of weight by treatment with hydrochloric acid, and the quantity of bases, calculated as carbonates, extracted by hydrochloric acid. A considerable portion of this deficiency represents organic substance. For this reason, the deficiency is greatest in the cases of the wholly disintegrated specimens which had been most exposed to the action of water. The constituents marked *a* were dissolved out by hydrochloric acid; those marked *b* were obtained from the residue.

				VII.	VIII.	IX.
a.	{	Carbonate of Lime	....	2.36	12.44	4.87
		" Magnesia	....	0.37	0.27	0.37
		Peroxide of iron	....	1.32	1.18	1.58
		Water *	....	0.71	2.60	1.21
		Loss ....	....	1.49	1.87	3.35
b.	{	Silica	....	51.59†	50.19‡	56.01
		Alumina	....	23.52	22.89	{ 20.64 2.50
		Peroxide of iron	....		
	{	Lime	....	8.76	trace.	....
		Magnesia	....	1.02	0.79	0.24
		Alkalies	....	8.86	7.77	9.23
					100.00	100.00	100.00

VII. Unaltered labrador. Although the crystals were very

* Estimated directly.

† According to a second estimation, 51.98.

‡ According to a second estimation, 51.46.

carefully selected, it is not certain that they were all equally fresh. The presence of carbonates, indicated by the effervescence with hydrochloric acid, showed that some at least were slightly altered.

VIII. Partially disintegrated labrador. There was no doubt that these crystals, and those represented by the following analysis, were not in the same stage of decomposition. Therefore, this analysis indicates only an intermediate state.

IX. Wholly disintegrated labrador.

The following table gives the composition of these three specimens of labrador, after deducting respectively the substances extracted by hydrochloric acid.

	VII a.	VIII a.	IX a.
Silica	54.44	61.47	63.24
Alumina	24.82	28.04	{ 23.51
Peroxide of iron			{ 2.86
Lime	10.31	trace.	....
Magnesia	1.08	0.97	0.72
Alkalies	9.35	9.52	9.67
	100.00	100.00	100.00

The comparison of VII with I, III, and IV, shows that the former specimen of labrador was somewhat altered. It approximates slightly to the specimen V, which was likewise decomposed, except that the amount of lime is much greater.

It is easy to recognize the course of the decomposition by means of these analyses. It is principally lime that is separated, and sometimes disappears entirely. Even in labrador that appears to be unaltered, a portion of the lime may have been converted into carbonate. The 12.44 per cent. of carbonate of lime in VIII, contains 6.98 lime, consequently 1.78 less than the lime combined with silica in VII; so that not only has all the lime in VIII been converted into carbonate, but nearly a fifth of this carbonate has been removed by water.

As the lime is removed from labrador, the amount of silica and alumina is relatively increased; but it must be remarked that in VII, the quantity of the latter is much less than in labrador, having the normal composition. The same relation is apparent in V. It would, therefore, appear that before, or with the separation of lime, a portion of the alumina was removed,

perhaps as aluminate of lime. In the analyses of some other specimens of labrador, the alumina amounts to 2 or 4 per cent. less than in normal labrador, while the amount of silica differs little from the normal proportion.

It is remarkable that the alkaline silicates have experienced so little decomposition. Perhaps their decomposition commences only after the perfect decomposition of the silicate of lime, and the removal of the resulting carbonate of lime.

The decomposition of labrador likewise takes place in another manner, as will be seen from the analyses X to XIII inclusive.

	X.	XI.	XII.	XIII.	XIV.	XV.
Silica	51.00	47.9	49.32	48.62	53.48	53.98
Alumina....	30.50	34.0	30.07	34.66	26.46	27.56
Peroxide of iron	1.75	2.4	0.70	0.73	1.60	1.14
Protoxide of manganese....	....	....	0.60	....	0.89	....
Lime	11.25	9.5	4.25	12.02	9.49	8.65
Magnesia ....	....	0.2	1.96	0.33	1.74	1.35
Soda	4.00	5.1	4.85	2.55	4.10	6.06
Potash ....	....	0.9	4.45	1.05	0.22	0.47
Water	1.25	....	3.15	0.50	0.42	....
	99.75	100.0	99.35	100.46	98.41	99.21
O. Q. ...	0.716	0.83	0.716	0.822	0.628	0.636

Analyzed by

- X. Felsite, a compact felspar from the green-stone slate of Siebenlehn, of which it constitutes the principal mass, together with scattered particles of hornblende

XI. Labrador from lava at Vesuvius

XII. Vosgite from the porphyry of Ternuay

XIII. A similar mineral from globular diorite in Corsica §

XIV. Labrador crystals, showing traces of decomposition from sand at the Val de Bove, Etna
- Klaproth.*

Elie de Beaumont, Laurent, and Ch. Holmes.†

Delesse. ‡

Abich.||

* Beiträge. vi, 259.
† Annal. de Chim. et de Phys. lx, 332.
‡ Journ. für prakt. Chemie xliii, 417, and xlv, 219.
§ Ibid. xlvi, 187.
|| Poggend. Annal. l, 347.

XV. Small crystals of labrador from an old } Analyzed by
lava in the Sandwich Islands } Schlieper.*

The oxygen quotients of the specimens X to XII inclusive, as well as those of II, correspond perfectly. As the latter is labrador, there is no reason why the former minerals should not be labrador. All three, however, were somewhat decomposed, as may be seen by the amount of water contained in X and XII.† The presence of water in II is not stated; probably its estimation was neglected.

The association of felsite with hornblende is not remarkable, because the opinion that labrador is associated only with augite, and not with hornblende, has been found erroneous. Klaproth's remark that the felsite analyzed by him was taken from decomposed rock, admits of the conjecture that the amorphous mineral was somewhat altered.

The oxygen quotients of XI and XIII, correspond with each other perfectly, and do not differ much from that of the previous specimen. Although the analysis XI is not exact, as the crystals were impure, and the amount of water is not stated, these two minerals appear to be labrador that is somewhat decomposed.

While the decomposition of the specimens of labrador, VII, VIII, and IX, consists principally in a total removal of lime, the specimens II, X, and XIII, contain almost the same amount of lime as the unaltered labrador. In XI, and particularly in XII, it is indeed somewhat less; but the amount of alkalies is proportionably greater. When the lime is perfectly removed, the amount of silica is relatively increased, as in VII, VIII, and IX. When, on the contrary, none of the lime or alkalies are removed, but the amount of silica decreased, as in II, X, XI, XII, and XIII, this diminution is not merely relative, and it is attended by a relative increase in the amount of alumina.

The decomposition of labrador is, therefore, the result, either of a total elimination of lime, or of a partial elimination of silica. In the former case, the decomposition would be effected by carbonated water, as is shown by the presence of carbonates in VII, VIII, and IX.‡ In the latter case it would be effected

* Dana's Mineralogy, p. 686.

† Rammelsberg regards XII as an impure and somewhat decomposed labrador.—Suppl. 4, p. 126.

‡ It appears worthy of notice that the labrador V, and some other specimens analyzed by Delesse, containing considerable quantities of potash nearly equal to the soda, are among those which contain the least lime. Perhaps the lime has been partially displaced by carbonate of potash, and silicate of potash substituted in the place of silicate of lime.

by water free from carbonic acid, removing silica probably as an acid silicate.* This removal would be facilitated by the soluble condition of the silica in labrador, and if the silica were removed in the state of acid silicates, analysis would of course indicate merely the diminution of silica.

It is very possible that the same water might effect both kinds of decomposition at different parts of the labrador; for if water with the ordinary amount of carbonic acid were brought in contact with labrador, its carbonic acid would be consumed in the formation of carbonates, and if the water were then to continue in contact with labrador, it would not remove any more bases, although it might dissolve silicates, and thus produce a relative diminution of the silica, if the silicates removed contained excess of acid.

There is no analysis of labrador that has been completely converted into kaolin. G. Rose† speaks of white kaolin, supposed to have originated from labrador. If the analysis of such decomposed labrador should indicate the presence of minute quantities of alkali, but no lime, it would confirm the above conjecture that the decomposition of the alkaline silicates is the last stage of the alteration of labrador.

The oxygen quotients of XIV and XV are so near the normal value, that the minerals cannot be much altered. The small amount of alumina in XIV is singular; but according to Abich, this may be owing partly to a small admixture of augite and partly to loss in analysis, as the deficiency amounts to 1.6 per cent.

The zeolites in the drusy cavities of amygdaloid rocks, appear to be products of the decomposition of labrador.

I.—ANORTHITE.

This mineral was first recognized as a distinct kind of felspar by G. Rose.‡ It is decomposed by hydrochloric acid, but the silica does not separate in a gelatinous state.

Occurrence and formation.—The anorthite in lava and volcanic tufa, &c., might be regarded as a product of fusion. However, the anorthite at Somma occurs either in drusy cavities of dolomite, or with augite and mica in the hollows of this rock. The remarks

* Further experiments must determine whether this conjecture is well founded. Perhaps it would be possible, by the long continued action of boiling water free from carbonic acid, to extract from labrador a sufficient quantity of substance for examination.

† Reise nach dem Ural. i, 344.

‡ Gilbert's Annalen. lxxiii, 173.

as to the formation of meionite* are likewise applicable to that of anorthite. These minerals are very analogous in composition. As they occur in the drusy cavities of the rock at Somma, fine specimens of which are in the collection of minerals at Berlin, they present in such a marked manner the characters of the substances imbedded in amygdaloid rocks, that there is not the most remote possibility of supposing they have a volcanic origin. The drusy cavities are never more than partly filled. The substance first formed is a greenish crust similar to the siliceous crust in the drusy cavities of amygdaloid rocks. This is followed inwards by augite, and then by anorthite or meionite, but they never occur together. In one specimen I found augite following meionite, and it was unquestionably a product of infiltration like the latter mineral.

Forchhammer states that in Iceland, anorthite occurs crystallized in a blackish brown tuff. Now as tuff is a sedimentary rock, although the material for its formation may be volcanic, it cannot be supposed that well-developed and unaltered crystals of anorthite could have been washed into it. Therefore its subsequent formation in the wet way is as little to be doubted as that of anorthite in dolomite. Moreover, the anorthite analyzed by Genth, occurs in an old lava at Hecla, so that there was ample time for the formation of this felspar.

Although there is little probability that anorthite is a volcanic product, it is a very important fact, that minerals containing silicate of lime such as this felspar, meionite, and even augite, may be formed in the wet way, not only in dolomite and granular limestone, but likewise in tuff and lava. As carbonate of lime removes carbonic acid from the water penetrating these rocks, silicates of lime may be deposited, and as the water which penetrates is free from carbonic acid, the silicates of lime that are formed do not undergo alteration.

The occurrence of anorthite in limestone, far distant from volcanoes,† is also consistent with this view.

Composition.—With the exception of some older and imperfect analyses, the whole of the published analyses of altered and unaltered anorthite are given. To these are added the analyses of lepolite, amphodelite, and the scapolite of Tunaberg described by Walmstedt, which are likewise anorthite; also the analyses of linseite and rosite, which are anorthite more or less decomposed.‡

* See Chapter xxix.

† See p. 214, Nos. vii, viii, ix, xi.

‡ G. Rose.—*Krystallo-chemisches Mineralsystem*, p. 89.—Breithaupt likewise regards linseite as decomposed lepolite.—*Journ. für prakt. Chemie.* xlvii, 236.

	I.	II.	III.	IV.	V.
Silica	44.12	43.79	47.63	48.75	45.97
Alumina	35.12	35.49	32.52	30.59	33.28
Peroxide of iron	0.70	0.57	2.01	1.50	1.12
Lime	19.02	18.93	17.05	17.22	17.21
Magnesia	0.56	0.34	1.30	0.97	....
Potash	0.25	0.54	1.09	1.13	1.85
Soda	0.27	0.68	0.29	0.62	0.69*
	100.04	100.34	101.89	100.78	100.12
O. Q.	0.970	0.978	0.884	0.806	0.889

	VI.	VII.	VIII.	IX.	X.
Silica	47.40	42.80	42.50	45.80	43.83
Alumina	30.45	35.12	33.11	35.45	35.28
Peroxide of iron	0.80	1.50	4.00	1.70	0.61
Lime	14.24	14.94	10.87	10.15	19.37
Magnesia	0.87	2.27	5.87	5.05	....
Potash	0.38	....	....	....	....
Soda	2.82	1.50	1.69	....	....
Water	2.00	1.56	1.50	1.85	....
	98.96	99.69	99.54	100.00	99.09
O. Q.	0.794	1.008	1.019	0.914	0.972

	XI.	XII.	XIII.	XIV.	XV.
Silica	44.90	44.13	42.22	40.90	42.09
Alumina	34.51	35.12	27.55	30.74	38.89
Peroxide of iron	0.69	0.96	6.98	....	....
Protoxide of iron ....	....	....	2.00	15.47	....
Protoxide of manganese	0.19	trace.	....	1.33	....
Lime ...	3.59	5.55	....	0.40	15.78
Magnesia	2.45	1.43	8.85	0.81	...
Potash ...	6.63	6.73	3.00	4.57	....
Soda	trace.	....	2.53	0.04	4.08
Water	0.53	5.29	7.00	5.57	....
	99.49	99.21	100.13	99.83	100.84
O. Q.	0.827	0.87	0.913	0.908	1.083

* Contained an admixture of augite.

	Analyzed by
I and II. Anorthite from Somma	Abich.*
III. Anorthite from Selfjall in Iceland	Forchhammer.†
IV. Anorthite from the Thjorsa lava at Hecla	Genth.‡
V. The same mineral	Damour.§
VI. Bytownite from Canada	Hunt.||
VII. Lepolite from Lojo in Finland	Hermann.¶
VIII. Lepolite from Orrijerfoi in Finland	
IX. Amphodelite from a limestone quarry at Lojo; probably from the same locality as VII, the fracture resembles that of wernerite	Nordensköld.**
X. Scapolite from Tunaberg	Walmstedt.††
XI. Rosite—rosellan—from a limestone quarry near Aeker in Södermannland. It is not crystallized, and appears to occur in another quarry	Svanberg.‡‡
XII. A similar mineral from the granite near Tunaberg in Södermannland. This mineral occurs in other quarries and together with amphodelite in a copper mine	Svanberg.§§
XIII. Linseite from a copper mine at Orrijerfoi in Finland	Hermann.||||
XIV. Iberite in large pale greyish-green crystals from Montoval near Toledo	Norlin.¶¶
XV. Indianite.—According to Brooke the directions of the cleavage planes are the same as in anorthite	B. Silliman and Brush.***

The two specimens of lepolite VII and VIII, are the only minerals, among those enumerated above, in which the oxygen

* Poggend. Annal. li, 519.

† Journ. für prakt. Chemie. xxx, 367.

‡ Annal. der Chemie und Pharm. lxvi, 18.

§ Bull. de la Soc. Géol. de France. Sér. 2, vii, 83.

|| Phli. Mag. Ser. 4, i, 322.

¶ Journ. für prakt. Chemie. xlvi, 387.

** Berzelius's Jahresbericht, xii, and Journ. für prakt. Chemie, xiv, 42.

†† Hisinger's Mineral-Geographio. German translation, p. 99.

‡‡ Pogg. Annal. liv, 268, and lvii, 170.

§§ Ibid. lvii, 175.

|||| Journ. für prakt. Chemie. xlvi, 393.

¶¶ Berzelius's Jahresbericht, xxv, 330.

*** American Journal. Ser. 2, viii, 15.

quotient amounts to 1; the oxygen quotients even of the anorthite I and II are somewhat under 1,* although the purest and most transparent crystals were used for analysis. These differences are however, so minute that the oxygen quotient of these five specimens of anorthite may be taken as 1. If this is the normal oxygen quotient of anorthite generally, the other specimens, in which it falls as low as 0.794, must be to some extent altered by loss of their bases. The lime varies most; in X it amounts to as much as 19.37 per cent., and in XIII it has been entirely removed. The amount of water is greater where the lime is below the normal amount; when the lime has entirely, or very nearly disappeared, it reaches its maximum as in XIII. Moreover, since the introduction of water, which is a concomitant of decomposition, is connected with the diminution of the quantity of lime, it would appear that this diminution is the main result of the decomposition. In XI and XII, which were formerly mistaken for amphodelite, the other characteristic of decomposition, the decrease of hardness, is recognizable according to Svanberg, so that it cannot be doubted that XI and XII are decomposed amphodelite.

Generally the quantity of alkalies and of magnesia increases as the quantity of lime diminishes; so that there is reason for the conjecture that these bases decompose the silicate of lime, and that this decomposition is effected by water containing alkaline carbonates and bicarbonate of magnesia,† the carbonate of lime being removed by the water. But the lime is not entirely replaced by alkalies and magnesia; and, consequently, the oxygen quotients are reduced. This may also be owing to the simultaneous decomposition of silicate of lime by free carbonic acid in the water.‡

In VIII, XIII, and XIV, which are characterized by a considerable amount of peroxide of iron, it is possible that this substance may have been substituted for, or have displaced, alumina.§ It is improbable that XIV would not have contained peroxide of iron together with protoxide. For this reason Rammelsberg|| conjectures that it approaches linseite; Naumann¶ considers it to be altered corderite, because its composition is similar to that of praseolite. If the former view is correct, it may be supposed

* It is remarkable that the anorthite III, although crystallized on all sides, and presenting very distinct faces, should have such a low oxygen quotient.

† English edition, i, 8, and 13, No. 16.

‡ Ibid. i, 2.

§ See ante, p. 74, No. 49.

|| Suppl. 4, p. 144.

¶ Lehrbuch der Oryktognosie. Ed. 3, p. 346.

that the silicate of lime has been decomposed partly by silicate of potash, and partly by hydrated peroxide of iron resulting from the oxidation of bicarbonate of iron in the water.*

Decomposition.—The results of incipient decomposition are manifested in anorthite by opacity or pearly lustre and by a thin white incrustation.

K.—SAUSSURITE, JADE.

This mineral is not acted upon by acids.

Occurrence.—In euphotide which may be regarded as a variety of gabbro.

Composition.—Only five analyses have been published.

	I.	II.	III.	IV.	V.
Silica	44·00	49·00	44·6	43·6	49·73
Alumina	30·00	24·00	30·4	32·0	29·65
Peroxide of iron	12·50	6·50	....	....	0·85
Oxide of manganese	0·05	..	....	....	trace.
Lime ...	4·00	10·50	15·5	21·0	11·18
Magnesia ....	....	3·75	2·5	2·4	0·56
Soda	6·00	5·50	7·5	....	4·04
Potash	0·25	....	....	1·6	0·24
Water and carbonic acid ....	....	....	....	....	3·75
	96·80	99·25	100·5	100·6	100·00
O. Q.	0·896	0·747	0·928	0·976	0·716

I. Saussurite from the Lake of Geneva	Th. de Saussure.†
II. Saussurite	Klaproth.‡
III. Saussurite from the euphotide of Mont Genèvre	} Boulanger.§
IV. Saussurite from the euphotide of the Orezza valley in Corsica	
V. Felspar from euphotide	Delesse.||

Such considerable discrepancies in the oxygen quotients cannot be altogether owing to defective analyses; there must be

* See ante, p. 77, No. 50.

† Journ. des Mines, xix, 205.

‡ Beiträge, iv, 271.

§ Annal. des Mines. Sér. 3, viii, 159.

|| Bulletin de la Soc. Géol. de France. Sér. 2, vi, 547.

some other reason. It will subsequently* be shown that diallage, which, together with saussurite, constitutes gabbro, is very liable to decomposition, and that the rock generally presents all the characters of more or less advanced decomposition. Moreover, gabbro is generally associated with serpentine, a rock which is merely a product of the alteration of other rocks. The euphotide examined by Delesse effervesces with acids. The carbonates are distributed throughout the felspathic matrix as well as the crystals of felspar and diallage. Between the planes of cleavage and cracks in the felspar crystals, there are small laminæ of talc, and between the minerals, small veins of serpentine. The latter are sometimes so abundant, that it is impossible to determine whether the rock is serpentine or euphotide.

The very unequal amount of lime in the minerals, and the frequent occurrence of calc-spar in the druses and veins of gabbro, are likewise in accordance with the decomposition of these minerals.

The oxygen quotient of saussurite varies between 0·976 and 0·716; in anorthite between 1·083 and 0·794; in labrador between 0·83 and 0·555, this latter being the oxygen quotient of a specimen of labrador from euphotide. Now, since the oxygen quotients of saussurite and of anorthite come within nearly the same limits; since, moreover, the analyses of both minerals, notwithstanding considerable discrepancies, present a general correspondence; there is some ground for the conjecture, that saussurite is merely decomposed anorthite, or perhaps even decomposed labrador. It remains for further observation to decide whether the crystal form of saussurite, which is only on probability referred to the rhombic system, will throw any light on this question.

L.—LEUCITE.

This mineral, when powdered, is completely decomposed by hydrochloric acid, the silica being separated in a pulverulent state.

Occurrence.—Most frequently in old lava at Vesuvius; less frequently in the more recent lava; in old lava near Rome, in Lipari, Owaihi, in lava dykes, peperine, and in pumice stone in the Papal dominions; in leucite rock near Rieden and Volkesfeld; in a very decomposed state in the masses of tuff near Bell, and the Lake of Laach; in leucite rock near Rome; and in the dolerite of the Kaiserestuhl. It has also been ejected from Vesuvius in considerable quantity on several occasions.

* See Chap. xxxv.

Composition.

	I.	I a.	II.	III.
Silica	53.75	53.50	54.00	54.50
Alumina....	24.62	24.25	23.00	23.50
Lime	22.11	19.09	22.75	20.16
	100.48	96.84	99.75	98.16
O. Q.	0.546	0.524	0.520	0.508

	IV.	V.	VI.	VII.	VIII.
Silica	56.10	56.05	55.81	56.22	54.36
Alumina slightly ferruginous	23.10	23.03	24.23	23.07	24.23
Peroxide of iron	0.95	....	....	0.48	....
Lime ....	....	trace.	....	0.23	....
Potash	21.15	20.40	10.40	13.26	16.52
Soda ....	..	1.02	8.83	6.40	3.90
Loss by ignition ....	....	....	....	not estimated	0.64
	101.30	100.50	99.27	99.66	99.65
O. Q.	0.503	0.497	0.529	0.509	0.536

I., and Ia. Leucite from Vesuvius.

II. Leucite from Albano, near Rome.

III. Leucite from Pompeii Klaproth.*

IV. Leucite from Vesuvius Arfwedson.†

V. Leucite from lava at Somma Awdejew.‡

VI. Glass leucite from lava at Vesuvius Abich.§

VII. Leucite crystals from Rieden.

They effervesced slightly with acid.

VIII. 364 leucite crystals from another rock at the same place.

They did not effervesce in the least with acids.

Since only the analyses V and VI indicate the presence of soda, it would appear that leucite sometimes contains only potash, and sometimes both potash and soda. In order to decide this point, I made the following analyses.||

* Beitrage, ii, 39 et seq.—It was in leucite that Klaproth discovered potash as a constituent of minerals.

† Afhandl. i. Fys. vi, 139.

‡ Poggend. Annual. lv, 107.

§ Geol. Beobachtungen, p. 128.

|| For the mode of analysis, see German edition, ii, 2288.

	IX.	X.	XI.	XI a.	XI.b	XI.c
Silica	57.84	56.49	57.28	58.10	56.45	56.32
Alumina	22.85	22.99	22.44	22.76	24.35	23.99
with traces of iron						
Peroxide of iron....	0.14	....	....	....	....	....
Lime	0.20	0.04	trace	trace	trace	trace
Potash	12.45	15.21	17.12	17.36	17.43	17.54
Soda	6.04	3.77	1.75	1.78	1.98	2.15
Loss by ignition....	0.59	1.48	1.41	....	....	....
	100.11	99.98	100.00	100.00	100.21	100.00
O. Q.	0.481	0.487	0.465	0.465	0.506	0.503

IX. 19 leucite crystals erupted from Vesuvius in April, 1845.

X. 5 leucite crystals erupted from Vesuvius in 1847.

XI. Fragments of leucite from the exterior of large crystal from Roccamonfina.*

- a. The same after deducting the loss by ignition.
- b. Fragments from the interior of the same crystal.
- c. Fragments from near the centre of the same crystal.*

After looking over the previous analyses, there can hardly be any doubt left that there is probably no specimen of leucite that contains potash only. Klaproth's analyses do not prove the contrary, because he judged of the absence of soda merely from the crystalline form of the alkaline salts. Nor can Arfwedson's analyses be of any avail in this respect, since, from the considerable surplus, they are probably incorrect. The other ten analyses, however, indicate the presence of soda, and sometimes in considerable amount.

The oxygen quotients even of the other analyses, approximate somewhat closely to 0.5, and those of the more recent analyses are so near this value, that it may be taken as the normal oxygen quotient. But in IX, X, and XI, the oxygen quotient is much below this, and the loss by ignition indicates the presence of water, so that some of the bases have been removed. This loss of bases is striking in IX and X, in leucite crystals that were erupted

* By an oversight, the quantity of silica was not estimated in these two anylyses previous to the treatment with hydrofluoric acid, so that it was ascer- tained only by difference.

Although the leucite was digested for twenty-four hours with hydrochloric acid, still the silica was treated with hydrofluoric acid, so as to make sure that there was no mineral undecomposed. This should never be neglected when, as in most instances, leucite contains particles of augite or of lava that cannot be perfectly separated.

from Vesuvius seven or nine years before this analysis was made. During this short period they could not have been sensibly altered; and must, therefore, have been decomposed when they were thrown out by the volcano. The external appearance was little altered, except in the case of XI, where the exterior crust was earthy, pulverulent, and entirely destitute of lustre.

The peroxide of iron, and the lime found in my analyses, undoubtedly originate from imbedded augite crystals which were decomposed when the mineral was acted upon by hydrofluoric acid.

Formation. – Leopold v. Buch* found in the centre of the fine leucite crystals from Civita, Castellana, and Borghetto on the Tiber, a black nucleus that was almost always present, and round which the crystals appear to have been formed. When this nucleus is large, the leucite does not always envelope it, and then it is connected with the surrounding rock, and is little distinguishable from it. Sometimes this nucleus consists of an augite crystal, and then the two ends frequently project beyond the leucite. V. Buch is of opinion that if the leucite was formed prior to the rock matrix in which it is imbedded, these nuclei, which are seldom wanting in the crystals, must likewise have been formed previously, and it is evident that the leucite must have been formed subsequently to the augite.

The edges and corners of these crystals are sharp and therefore it cannot reasonably be supposed that they existed prior to the solidification of the rock matrix, for in that case the crystalline form would have been destroyed and irregular globular masses formed. It would, therefore, appear that the leucite has originated from the flowing lava.

Breislak† examined six of the finest crystals of leucite the surface of which did not present the slightest crack. In three of them he did not find any foreign substance; but in two there was a black earthy substance having perfectly the appearance of lava. On breaking one of these crystals, a white glass mass was discovered in the interior, and at the centre two microscopic fragments of augite surrounded on all sides by leucite. The leucite crystals from the lava boulders near Rome, frequently contain granules of augite, small fragments of lava, and more rarely granules of hauyn.

The occurrence of leucite in old lava, and particularly in that

* Gilbert's Annal. vi, 53 et seq.

† Lehrbuch der Geologie. German translation, iii, 292.

which belongs to periods far anterior to history, while it either does not occur in more recent lava, or the crystals are smaller and less perfectly developed, is regarded by v. Buch as very remarkable. Neither the lava erupted in 1794 nor that erupted in 1760 from the Torre del Greco, contain a trace of leucite. On the contrary the lava of 1767 is covered with a number of small white specks, and a still greater number of shining points are disseminated throughout the entire mass. By the aid of the microscope both of them are found to be perfect crystals of leucite.

The older lava, in which large crystals of leucite occur, constitutes considerable masses which extend over large spaces, and do not present any of the characters of lava streams. The large masses ejected from Vesuvius frequently contain crystals of leucite, in such quantity as quite to surround the crystals of augite. The fact that these masses of leucite never occur in lava streams, but only in the large masses of rock thrown out by the volcano is considered by v. Buch as an indication that the leucite is never formed in the interior of the volcano, but that it is probable its formation requires the presence of some substance that exists only outside the volcano, and is probably derived from the atmosphere.

The lava currents of 1822, 1828, and 1832, show that the leucite, which is peculiar to Vesuvius and to the volcanic regions of the Italian peninsula, occurs not only in the old lava but likewise to a considerable amount in the more recent and even most recent lava. Thus for instance Monticelli and Covelli* estimated the proportion of the leucite in the eastern lava of 1822, at 6 to 1 of the other ingredients. A lava erupted from Vesuvius in 1822 and in which leucite preponderates, presents distinct indications of having undergone a further influence of heat in the crater. The granules of leucite melted at the surface, covered the mass with a bluish-white coating. Another lava of this kind had acquired a vitreous state. Among the aggregated masses thrown out from Vesuvius, is an amygdaloid lava containing white granules of leucite, also fragments of porphyritic lava consisting of augite with a larger quantity of leucite like that of the old lava stream at the northern declivity of Somma, and a leucite lava in which crystals of leucite $\frac{1}{2}$ an inch in diameter were imbedded. In the blocks that fell two miles south-east of the crater, consisting of half vitrified, porphyritic lava the largest of which had a diameter of $1\frac{1}{2}$ inch; and in the fragments of scorixæ accompanying them, which contained distinct crystals of augite; and in the pumice stone, the leucite preponderated over

* Der Vesuv. German translation, p. 154.

the augite and mica. Likewise the fine sand that fell in October 1822, contained granules of leucite amounting to 0.33 of the whole and sometimes to more than in any of the other substances.

F. Hoffmann* found upon the steep walls of the fissure that had been made in the outer ridge of Vesuvius, by the lava streams of October and December 1831, a great number of lava banks lying parallel one above the other, and full of leucite substance with imbedded crystals of augite. These walls are frequently traversed, perpendicularly or at a great inclination, by lava dykes the substance of which is quite like that at Monte Somma, containing granules of leucite and augite. Fresh scorïæ, from a lateral branch of the lava, which had penetrated an adjoining fissure, contained threads of glass in all the cavities, and in the interior leucite granules could be distinctly recognized. In some he saw the commencement of crystallization, consisting of five or six closely aggregated globules, sometimes the small cavities were lined with a thin drusy crust of small leucite crystals. The fragments of lava erupted on the 23rd February, 1832, deposited by Hoffmann in the Berlin collection, contain a number of leucite granules and crystals and augite. Even in the pieces of lava pressed flat by iron tongs and marked with the name Salvatore Madonna, 1832, small leucite granules may be recognized; but the augite is developed only in the porous edges. The compact lava with thick crusts of chloride of sodium taken from the crater on the 25th March, 1832, presents very distinct crystals of leucite. The porous lava of the 22nd March, 1828, in which the augite crystals project from the surface with sharp outlines or covered with a thin coating, likewise contains large crystals of leucite. This is also the case with vesicular lava from the surface of an older lava stream from the Fosso di Pollena which however contains but very few distinct crystals of augite.

Necker† states that the section of a lava stream at Vesuvius is covered at the surface with homogeneous scorïæ that had solidified suddenly by contact with cold air. Towards the interior the cavities are less frequent and smaller, and the mass presents a more distinct rocky structure. Small granules of leucite and augite may be recognized by means of the magnifying glass; and they are larger in proportion to the distance from the surface.

The leucite crystals thrown out in such large quantity from Vesuvius on the 22nd April, 1845, are according to Pilla's descrip-

* Archiv. für Mineral. etc. xiii, 183 et seq.

† Sammlung von Arbeiten ausländ. Naturforscher über Feuerberg. German translation by Nöggerath and Paul, ii, 123.

tion* very translucent with a vitreous lustre and are remarkably regularly developed and perfect. The largest are about the size of small nuts, and small particles of fresh scoriz are sometimes attached to them. Augite crystals 7 millimetres in length were thrown out together with these crystals of leucite.

I obtained 19 of the leucite crystals above described, and likewise some others said to be from the eruption of the 10th February, 1847. They were both so much alike, that they might have been supposed to have the same origin. They were regularly developed, very translucent, with vitreous lustre, and quite perfect. Some of them had at places a thin coating, here and there glassy, brownish-yellow or brown, and more rarely of a greenish colour, more especially where two or three crystals were attached. Upon one crystal was a vesicular scoria, with vitreous lustre, showing distinctly that it had been in contact with a melted mass. Other of the crystals were quite free from such incrustation, and quite pure at the interior. When broken, however, there were found in most of the crystals, imbedded substances, which sometimes presented distinct indications of previous fusion, and consisted of the same substance as the scoriz adhering to the exterior. I was unable to detect any fragments of augite in these crystals. The crystals of leucite thrown out by Vesuvius, and described by Pilla, appear to have been very similar to these.

The leucite crystals of Roccamonfina are sometimes as large as a full sized orange.† They are of the usual form, well-developed, and only slightly disintegrated. Pilla observed upon the surface of one of these crystals, small serpulæ, and grains of sand similar to those which are so frequent upon shells in sand banks. He infers from this, the submarine origin of the crater of Roccamonfina.

A fragment of leucite crystal from this place, about three-quarters of an inch in diameter, broke with a slight blow; a crust was detached from it, rough at the outer surface, with a vitreous lustre at the inner surface, and translucent at the edges; it broke down between the fingers into small fragments, mostly smaller than peas, and seldom presenting regular faces. This crust did not contain any imbedded substances, and only here and there presented small brownish specks. The substance beneath it was still more easily broken up into fragments that were either trans-

* Jahburch für Mineral. 1846, p. 341.

† Pilla.—Loc. cit.

parent, translucent, or opaque. The nucleus contained a number of imbedded masses which had the colour of augite, but did not present any recognizable faces. Some of them contained microscopic white particles of leucite, others were intimately mixed with leucite, and had a grey colour, while here and there, veins of leucite ran through them.

I made a careful examination of a great number of leucite crystals from the leucite rock at Rieden, near the Lake of Laach. They were mostly very small, the largest being only a line in diameter, and those from another rock much smaller, 364 of them weighing only 39 grains. Some of these crystals were covered with a very thin crust of kaolin, but were perfectly unaltered at the interior. Scarcely any of them are without imbedded black particles resembling augite. These particles are neither perfect crystals, nor round globules, such as are formed by melting augite by the aid of the blowpipe; even the smallest of them appear, when magnified, as fragments of crystals, with straight edges and sharp corners. They not unfrequently form needles as thin as a hair, and as long as the crystals are thick. They are very frequently ochre colored, owing to incipient decomposition.

The substances imbedded in the leucite of Rieden are, therefore, very different from those in the crystals of leucite from Vesuvius, and the large leucite from Roccamonfina, in none of which was there any trace of the formation of crystals to be found, but merely substances resembling lava. In one specimen of ground and polished leucitic lava from Vesuvius, containing leucite crystals three lines in diameter, there are some black specks, but no crystals.

The augite is not so abundant in the leucite rock of Rieden as in the crystals of leucite. In the former case, distinct corners, edges, or faces, are rarely recognizable; there is barely any difference in point of form between the augite; but in the rock, the imbedded masses are sometimes as large as the larger crystals of leucite, although they are generally very small. Sometimes the augite contains small particles of leucite, and the smallest cracks are filled with it. Some of the larger augite masses are globular, with a vitreous lustre, and are separable into concentric layers; some appear to have interfered with the development of the leucite crystals associated with them. Isolated crystals of vitreous felspar are much less frequent than leucite; they likewise often contain imbedded fragments of augite.

All these circumstances tend to show that the augite in the

leucite crystals, like that in the rock, was formed first; the leucite substance in the interior of the augite, and in the cracks, is evidently of more recent formation than the augite.

Leucite does not melt before the blowpipe; augite, on the contrary, melts to a glass. Klaproth found, that when leucite was exposed to the heat of a porcelain furnace, there was a slight fusion at the surface, but at the interior, only a very slight alteration, accompanied by an increase of lustre; the imbedded hornblende (augite?) was however, melted*, so that leucite is much less fusible than augite.

I exposed three large pieces of leucite rock from Rieden to a high temperature in a Hessian crucible. The mass rose up and flowed over, owing undoubtedly to evolution of carbonic acid as the rock effervesces copiously with acid. The portion that remained attached to the side of the crucible was a perfectly melted vitreous mass, in which the leucite crystals appeared almost unaltered, as was mostly the case with the portion that flowed over. Some of the leucite crystals had, however, become vesicular, and resembled pumicestone, which might be owing to the presence of augite in them, or to the fluxing action of the surrounding mass.

This experiment was repeated with fragments about the size of peas; they melted, forming a vesicular scoria, which rose four inches in the crucible, and flowed over. The leucite crystals were not melted, but were mostly milk-white, and some had a vitreous lustre. At one part where the mass had been melted to a perfect glass, the leucite crystals could be distinctly recognized.

Finely powdered leucite rock was then exposed to the influence of a powerful fire. Upon breaking the crucible, a vesicular mass was found at the centre surrounded by an aggregated but not vesicular crust, which is remarkable as the heat must have been greatest at the exterior. In this crust the particles of augite were distinctly separate from those of leucite; the former melted to globules and the latter mostly unaltered, sometimes surrounded by a yellowish glass. The leucite granules were likewise distinctly recognizable in the central mass. The mass of the rock must, therefore, have been so liquid that the numerous cavities with very thin sides, upon which the leucite was situated, could be formed.

The difficult fusibility of leucite compared with that of the rock in which it is imbedded, indicates that if it has crystallized from melted lava it would have solidified first, and that the lava

* Beiträge, i, 21.

inclosed in the crystals of leucite would have solidified much later.

The case is different when as v. Buch states, an augite crystal is imbedded in a crystal of leucite. The above experiments show that augite is more fusible than leucite; so that the augite in this case cannot have been formed prior to the leucite, in which it is imbedded. Augite may crystallize when slowly cooled, so that it may be supposed that a mass of augite inclosed in a crystal of leucite would likewise crystallize afterwards. But it is difficult to understand that in this case a mass of augite thus inclosed in a crystal of leucite, would have sufficient space for assuming a crystalline form, or that the thin needles above mentioned, could have been formed.*

Although considerable force is developed in crystallization, it does not cause the crystal to penetrate solid substances which interfere with their formation, as in the freezing of water, the ice crystals do not penetrate the sides of the vessel containing the water, but it bursts. It might, therefore, be expected that the liquid augite inclosed in the crystals of leucite would have rent them in crystallizing, especially since the surrounding mass being more fusible than augite, would not have been any obstacle in this respect.

It is still less possible to imagine that crystals of augite could have escaped fusion when surrounded by a melted mass of leucite, or at least, that their edges and corners would not have been rounded.

Although I agree with v. Buch in the opinion, that the leucite has been formed after the augite imbedded in it, I cannot reconcile this order of succession in the formation of these minerals with the separation of leucite from liquid lava. He places great stress upon the fact that the more recent lava does not contain leucite crystals of such size and perfect form as are found in the older lava. But I have already † alluded to the supposition which, from his view of the case, would be unavoidable, that the conditions for the formation of these minerals by fusion have ceased to exist at Vesuvius, and I must again return to this point in regard to the formation of leucite.

Leopold v. Buch was conscious that the formation of leucite

* Breislak has already pointed out this difficulty.—Loc. cit. i, 526.—He says, "The small particles of augite, and even of felspar must have solidified before the leucite in which they are imbedded, and which is much less fusible than either."—He attempts to remove this difficulty, but in so fantastic a manner that refutation would be superfluous.

† See ante, p. 94.

cannot be accounted for by the phenomena presented at first sight by the rocks in which it occurs, and he assumed that some further condition must have been concerned. This condition I am unable to imagine other than the action of water. It was in this way that the constituents of leucite were dissolved and crystals formed in the lava. Such a mode of formation at once accounts for the occurrence of larger and more fully developed crystals in the old lava, than in that which is of more recent date. The microscopic crystals of lava scattered throughout the lava of 1767 and 1779 at Vesuvius, would, according to this view be in the early state of formation. The small particles of leucite in augite, and the cracks of augite crystals can only have been introduced by water.*

The leucite lava, therefore, presents the character that has so frequently been spoken of, and which is, perhaps, common to all volcanic rocks, that the crystallization has taken place long subsequent to solidification. The presence of peroxide of iron in the minute fissures in leucite lava from Vesuvius, and the conversion of the augitic particles in the crystals of leucite into a red substance, show that the action of water upon this rock has continued after the formation of augite and leucite crystals. Cavities full of water are not uncommon in lava, and are frequent in the lava at Capo di Bove near Rome, as well as in some of the lava at Somma.

The sound condition of the leucite crystals in the melted lava, in the experiments above described, weakens the force of the argument brought by v. Buch against their pre-existence. If the crystals of leucite remained unaltered in a melted mass that was so liquid as to have been perfectly vitrified at the sides of the crucible the possibility of the existence of these crystals in melted lava is greater because the temperature to which the leucite rock from Rieden was exposed, was far greater than that of melted lava at Vesuvius. The lower the temperature of this lava the less probability would there be that the crystals of leucite would be affected in any way.

Medici Spada found in the lava at Borghetto, crystals of leucite, which not unfrequently appeared as if they had been split, but without being in any way defective. The lava had penetrated into the fissures, evidently showing the existence of the leucite crystals in the liquid mass. It is impossible to suppose that crystals formed in the liquid lava should have been split while the mass was still liquid, although this might have happened after the solidification of the lava, but then the lava could not have penetrated

* As to the action of water upon leucite, see English edition, i, 59.

the fissures. It is, however, very possible that the crystals of leucite were enveloped by the liquid lava, and cracked in consequence of the sudden heating, in which case the lava would have penetrated into the fissures.

In the leucitic porphyry of Roccamonfina, Sacchi found together with large perfect crystals, others that were rounded, or fragments of all sizes and shapes.* It is impossible to suppose that in a liquid mass crystals of leucite could be formed and then rounded or broken into fragments. A rock in which such fragments or rounded leucite crystals occur, cannot be other than a sedimentary rock that has been formed from volcanic products. Pilla compares it to leucitic tuff, and the presence of the small serpulæ as well as the small grains of sand upon one of the large crystals of leucite renders this probable. Moreover, the large crystals of leucite associated with the broken fragments could not have been preserved, and since the rock containing these large crystals occurs mostly at the outer declivity of the large cone of Roccamonfina, there is no other than the wet way by which we can suppose the formation of these crystals to have taken place.

It would appear, therefore, that this cone consists of substances derived from leucitic rocks by disintegration, and deposited by water, so that together with fragments of leucite crystals, there are crystals that have been perfectly restored in the wet way.

On the contrary, the description given by Neckert† of the occurrence of leucite in the lava of Vesuvius, and the greater size of the crystals towards the interior, would appear to indicate their separation from an homogeneous melted mass. As a consequence of the remarks already made‡ as to the solidification of melted masses, it may be easily understood, that in a homogeneous lava, the constituents of the less fusible leucite might combine, and crystallize first, and that afterwards the more fusible matrix would solidify. Such a separation of leucite might take place in the masses of lava solidifying in the crater, and as the solidification would in such case be very gradual, there would be the most favourable conditions for the formation of large crystals of leucite.

A large amount of alkalis and of alumina in lava, determines the formation of leucite. In augitic lava, the alkalis amount to 4.22 or 4.92 per cent., the potash amounting to only a small

* Eichwald.—Nouveau Mém. de la Soc. imp. des Natural. de Moscou, ix, 270

† See ante, p. 223.

‡ Ibid. p. 93.

fraction of the soda, while in the lava at Vesuvius, the alkalies amount to as much as 10·43, or 11·84 per cent., the potash being about one-third of the whole quantity. Therefore the former lava gives rise to the formation of labrador poor in alkalies, and the latter gives rise to the formation of leucite. Since the other constituents of augitic and leucitic lava are much in the same proportion, augite is formed in both cases, besides these very different felspars. Such considerable proportions of alkalies as are contained in the lava at Vesuvius, are very rarely met with in rocks, and for the same reason, leucite rocks are very unfrequent.

The intumescence and overflow of the melted leucite rock with its imbedded crystals of leucite, show that, in a similar manner, lava containing crystals of leucite might issue from the crater of Vesuvius, and flow along an inclined surface. Hence it is easy to account for the presence of granules of leucite in the scorïæ that solidified during Hoffmann's stay at Vesuvius, as well as in the flattened pieces of lava. The occurrence of glassy threads, together with granules of leucite, indicate very rapid solidification, during which it is scarcely probable that the crystallization of leucite could have taken place.

Most of the circumstances above described afford evidence of the formation of leucite in the wet way rather than by fusion. However, since many substances may be formed in both ways, there is no reason why this may not be the case with leucite. If it is necessary to assume the prior existence of the leucite crystals thrown out from Vesuvius, the question of their formation in the crater still remains to be solved. The activity of this volcano is frequently suspended for a long time; during these periods of inactivity great alterations take place in the crater; fissures through which lava formerly ascended are closed, while fresh channels are formed. During the very slow solidification of the masses of lava filling these fissures, the conditions are much more favourable to the formation of crystals, than in the lava at the outer declivities. When channels remain closed in this manner for centuries, the evolution of vapour from other fissures, and the meteoric water penetrating the mass, will likewise contribute to the formation of crystals. Then if it should happen that fresh lava is forced into these closed channels, heating the solidified masses to such a degree that the matrix melts, or is softened, while at the same time compressed and heated water-vapour forces a way through the mass, it may be imagined that crystals, with adherent portions of liquid lava, might be thrown out from the crater. These adherent

portions of lava would solidify during their flight through the air and form vesicular scoriæ, whether remaining attached to the crystals of leucite or not. As the leucite crystals IX and X had lost a portion of their bases, there is great reason to suppose that they had long been in existence in the crater, and even undergone some decomposition. Very probably they were imbedded in lava that had been solidified, and to which water or water-vapour had access. A stronger proof of their anterior existence cannot be found.

The opinion held by Monticelli and Covelli, that the shining envelope of leucite crystals is owing to a superficial fusion, I am unable to admit. It appears certain that it was merely the adherent portions of melted scoriæ which became vitreous by rapid cooling, for in the fusion experiment with the leucite rock, the same envelope was observed on the leucite crystals, although they were quite unaltered.

If the existence of leucite in the lava, solidified in the crater of Vesuvius is certain, it is likewise the case with regard to the crystals of augite thrown out at the same time. Consequently the heat cannot have been so great that the augite crystals were melted, but merely the more fusible matrix in which the crystals were imbedded. The volcanic sand, such as that at Stromboli, has probably originated from this melted substance by rapid cooling and solidification in the air. But it may also be supposed that the solidified lava is disintegrated by the action of strongly heated vapour without being melted, and that in this way the matrix may be thrown out in small fragments together with the crystals of augite and leucite. According to Pilla, the augite crystals from the eruption of the 22nd April 1845, are more or less disintegrated; some are blackish-brown, other reddish-brown or yellowish-white. These colours indicate peroxidation of the iron, which, even if atmospheric air was entirely excluded, may be the result of the action of water vapour.

It is well known that crystallization from water solutions is facilitated when crystals that are identical with the dissolved substance are immersed in the solution. This may be ascribed to an attraction between similar molecules, but the same effect is produced by solid substances of a different nature.

In conformity with these facts it may be imagined that the fragments of lava and augite, as well as the crystals of augite, imbedded in leucite crystals, would serve as nuclei of crystallization, which, however, did not take place by fusion, because the

leucite is much less fusible than the substances it incloses, and, consequently, they could not in that case have been in the solid state, while on the other hand, liquid substances would not serve as nuclei and promote crystallization, so that all the facts tend to show that the crystallization took place in the wet way. In this case the leucite crystals which existed in the liquid lava might, even if they had been merely small particles, have served as nuclei from which the crystallization commenced as in the case of water solutions.

The formation of crystals in solid rocks, into which no extraneous substance is introduced, and from which no substance is extracted, consists merely in a transfer of similar ingredients scattered throughout the entire mass, the crystals of gypsum, often of large size, that are found in marl, clay, compact gypsum, limestone, etc., have been formed by the segregation by means of water of the gypsum substance disseminated throughout these rocks, and the leucite crystals in the rock at Roccamonfina have been formed in the same manner.

Felspar with the form of leucite.—Sacchi found leucite crystals, the interior portion of which consisted of small regular shaped transparent crystals of ryakolite. Silliman likewise describes such a mineral and Blum * detected it several times in old lava.

The altered leucite crystals consist of a granular aggregate, with cavities, that do not present any crystals; some of the granules however present very smooth and brilliant faces of cleavage.

Blum is of opinion that the product of alteration is glassy felspar, more probably than ryakolite; this must be determined by analysis. Deducting the constituents of glassy felspar from those of leucite, the alteration would appear to consist in the elimination of an alkaline aluminate.

			Leucite.		Felspar.		
Silica	....	....	8 eqts.	—	8 eqts.	=	0
Alumina	....	....	3 „	—	2 „	=	1 eqt.
Alkalies	....	....	3 „	—	2 „	=	1 „

The decrease of weight would in this case amount to 14·81, and that of volume to 16·94 per cent; hence the cavities in these pseudomorphs may be accounted for. It has already been shown that the separation of such an alkaline aluminate may really take place.†

The smaller proportion of alumina and of alkalies in the leucite

* Nachtrag. 2, p. 23.

† See ante, p. 65, No. 39.

crust XI as compared with that in the unaltered leucite XI *b* and XI *c*, admits of the supposition that there had been a separation of alkaline aluminate.

The further this alteration had progressed the nearer would be the approach to the composition of glassy felspar. There is, however, this difference, that the alteration in this instance commenced at the exterior, while in the mineral described by Sacchi it took place at the interior. If the alteration has taken the same course in the other leucite crystals at Roccamonfina, and has been completed, the products of alteration would be found under the exterior crust.

These pseudomorphs are very interesting, not only because they furnish an example of the conversion of one kind of felspar into another, but also because they show that in lava, as in other rocks there is a constant process of alteration, and that leucite under certain conditions yields material for the formation of other minerals. Whether or not the glassy felspar that occurs, together with leucite, in the lava of Vesuvius is likewise a product of alteration requires further investigation. It is at least unquestionable, that glassy felspar may be formed by the partial elimination of alkaline aluminate from crystallized leucite, or from an amorphous leucite mass.

Kaolin with the form of leucite.—The alteration commences at the surface and extends inwards; the crystals first become dull, opaque and covered with a white earthy crust. The form is retained even when the decomposition is complete, but is destroyed by the slightest pressure.* In this alteration concentric layers of leucite present themselves. When the opaque, earthy crust is removed the transparent nucleus has the perfect crystal form of leucite. The leucite of Frascati, Albano, and Rome, are in various stages of alteration. No analysis of this kaolin has been published.

M.—NEPHELINE AND ELÆOLITE.

These minerals are completely decomposed by acids, the silica separating in a gelatinous state.

Occurrence.—Nepheline occurs in the nepheline rock near Löbau in Upper Lausatia, near Meiches in the Vogelsgebirge, Schreckenstein and Vierzehngebirge in Bohemia, in dolerite at the Katzenbuckel in the Odenwald, near Tentelburg in Westphalia, Tiechlowitz in Bohemia, Baigory in the Pyrenees, in the trachyte near Costebelle in France, in the glassy felspar rock at the Lake of Laach, in old lava at Aich near Andernach, at several places in

* Blum.—Die Pseudomorphosen, p. 79.

the Pontifical States, in the Val di Noto in Sicily, and in drusy cavities in the dolomite at Monte Somma.

Elæolite occurs in zirkon-syenite at several places in Norway, in the miascite of the Ilmen mountains, in mineral deposits near Degeröe in Finland, at Lichtfield in Maine, U. S., and at the Ozark mountains in Arkansas.

Composition.—Nepheline and elæolite, several analyses of which have already been given,* are characterized by great uniformity of composition and of their oxygen quotients.

	Analyzed by	O. Q.
I. Nepheline from Monte Somma	Arfwedson †	0·915
II. The same	} Th. Scheerer ‡	0·919
III. The same		0·899
IV. The same		0·937
For this analysis the purest nepheline, that was completely composed by hydrochloric acid, was selected, while the minerals presented by II and III contained from 3 to 5 per cent. of undecomposable admixture. Therefore the oxygen quotient of IV is most correct.		
V. White nepheline from Katzenbuckel	} L. Gmelin §	0·931
VI. The same	Scheerer || ....	0·909
VII. White elæolite, very pure, from Miask	} Bromeis ¶	0·944
VIII. The same		0·980
IX. The same	Francis **	0·912
X. The same	Scheerer ††	0·904
XI. Green elæolite from Fredriksvärn, Norway	} C. Gmelin ‡‡	0·949
XII. The same	} Scheerer §§	0·870
XIII. The same		0·875
XIV. Brown elæolite from Fredriksvärn	} Francis ||| ....	0·875

* See ante, p. 145.

† Schweigger's Journ. xxxiv, 207.

‡ Poggend. Annal. xlix, 364.

§ L. Gmelin and Leonhard.—Nephelin im Dolerit vom Katzenbuckel, 1822.

|| Loc. cit. 367.

¶ Poggend. Annal. xl, 577.

** Ibid. xlix, 364.

†† Ibid.

‡‡ Schweigger's Journ. xxxvi, 82.

§§ Ibid. 360.

||| Ibid. 362.

	Analyzed by	O. Q.
XV. Brown elæolite from Fredrik- svärn	} Scheerer*	.... 0·859
XVI. Dirty brownish, amorphous elæolite with uneven fracture from Brevig, Norway		
XVII. The same	Scheerer†	.... 0·880

The oxygen quotient does not in any one of these minerals, amount to 1, that of VIII is the highest. It is possible that the oxygen quotient of perfectly unaltered nepheline or elæolite is 1, as is assumed by some chemists who have assigned formulæ to these minerals. It is at least certain that those specimens of elæolite in which the oxygen quotient is below 0·9, have lost more or less of their bases. These specimens also contain the greatest amount of water, as for instance XV and XVI from 2·05 to 2·10 per cent., while the others are either anhydrous—VII, IX and XIV, or contain less than 1 per cent. water, V alone contains 1·39 per cent.

The nepheline from Monte Somma, that from Katzenbuckel, and the white elæolite from Miask, have the highest oxygen quotients; the green and brown elæolite have the lowest oxygen quotients; XI is an exception, but the correspondence between XII and XIII admits of the suspicion that the analysis of XI is inaccurate. It would appear, therefore, that the decomposition is accompanied by a loss of the white colour.§ An exact determination of the hardness of the different varieties would be very desirable for the purpose of ascertaining whether it bears any relation to the colour of the mineral.

The nepheline from Monte Somma and that from Katzenbuckel contain the largest amount of lime, from 0·84 to 2·01 per cent.; elæolite contains 0·20 to 0·81 per cent. This base, therefore would have but a small influence upon the oxygen quotient, and its removal by water would not cause any sensible reduction.

Bromeis found minute quantities of hydrochloric acid in nepheline and elæolite, and Scheerer likewise found sulphuric acid.

* Schweigger's Journ. xxxvi, 362.

† Ibid. 359.

‡ Ibid. xlv, 291.

§ Scheerer states that the silica separated from green and brown elæolite retains these colours, which can be removed only by nitric acid, or by ignition. It would therefore appear that they are owing to the presence of organic substance, introduced by water, and this would likewise indicate that decomposition had commenced.

The nepheline from Monte Somma contains the largest amount of hydrochloric acid, 0·22 per cent., and of sulphuric acid, 0·1 per cent.

Conversion of nepheline into natrolite.—This alteration has already been described.*

Conversion of giseckite into mica.—Blum† showed that the giseckite which occurs in porphyritic boulders‡ at Tgalikko-fjord in Greenland, is a mineral that is being converted into mica and which would appear most frequently to present indications of having been formerly analogous to pinite.

	I.	II.	III.	III. <i>a</i>
Silica	46·08	48·0	44·19	44·76
Alumina	33·83	32·5	36·77	36·34
Peroxide of iron	3·36	4·0	1·71	1·83
Oxide of manganese	1·16	...	...	...
Magnesia	1·20	1·5	1·39	1·27
Potash	6·20	6·5	9·79	10·00
Soda ....	...	...	1·00	0·84
Loss by ignition	4·89	5·5	5·15 §	4·96 §
	96·72	98·0	100·00	100·00

I. Giseckite

Stromeyer ||

II. Giseckite

Pfaff ¶

III and III *a* Liebenerite from the
felspathic porphyry of Monte
Viesena in the Tyrol

} Marignac **

Haidinger †† and Breithaupt ‡‡ consider this mineral to be a pseudomorph after nepheline; Marignac considers it to be pinite.

The comparison of I and II with the analyses of elæolite I, II, and III, §§ will show that in this alteration soda and lime are eliminated, while water, protoxide of iron, and magnesia are introduced. The composition of giseckite approximates very closely to that of potash mica, containing only a small amount of iron, except that the amount of potash in mica is rather larger. The considerable

* See ante, p. 145.

† Nachtrag 2, p. 131.

‡ According to Stromeyer, hornstone and clay-porphry.

§ Water and carbonic acid.

|| Gilbert's Annalen. lxiii, 372.—Stromeyer considers this composition imperfect, because he was unable to effect a perfect separation of the fine particles of felspar disseminated throughout the mass of the rock.

¶ Schweigger's Journ. xlv, 103.

** Archives des sciences physiques et naturelles, vi, 293.

†† Uebersicht der Mineral. Forschungen, 1843, p. 36.

‡‡ Handbuch der Mineralogie, iii, 475.

§§ See ante, p. 145.

deficiency in the above analyses may, however, arise from a defective estimation of potash. The chemical analyses of giseckite, whether imperfect or not, at least confirm Blum's description of this instance of pseudomorphism.

The similarity in point of composition between giseckite and liebnerite is unmistakable; the total amount of alumina and peroxide of iron is the same in both, but the amount of potash in the latter mineral is greater than in the former. But this difference may be owing to the probable defective estimation of the potash in giseckite.

In other respects the conversion of nepheline into liebnerite cannot be accounted for by a mere elimination of soda; a portion of this base must have been replaced by potash. As the liebnerite is associated with felspar crystals whose dark flesh-colour indicate a very advanced stage of decomposition and the consequent formation of carbonate of potash, it is all the more probable that water containing carbonate of potash has effected a displacement of some portion of the soda.* The evolution of some carbonic acid from liebnerite, when immersed in hydrochloric acid shows that the small, but never-failing amount of lime in nepheline, has in the course of this alteration been eliminated as carbonate of lime.†

The *davyn* of Vesuvius, occurring in lava and in the drusy cavities of masses ejected from Monte Somma contains, according to Mitscherlich, the same constituents as nepheline, together with small amounts of chlorine and lime, but no water, and as its crystallographic characters correspond, according to G. Rose, with those of nepheline, while at the same time it effervesces with acids, it would appear to be nepheline in a state of decomposition.

In the conversion of nepheline into giseckite it is possible that a portion of the soda of the former mineral may be displaced by potash, if, as is probable, the estimation of potash in the analysis of giseckite is defective. There would not in this case have been any deficiency of carbonate of potash, for the giseckite contains minute particles of felspar disseminated throughout the mass. Therefore, in accordance with these considerations, giseckite and liebnerite would no longer be regarded as individual minerals.

* See ante, p. 65, No. 38.

† Liebnerite is not completely decomposed by hydrochloric acid; and v. Kobell states that giseckite is little acted on by acids, while nepheline and ~~elsolite~~ *elsolite* are perfectly decomposed by acids.

It has already been stated that sodalite is to be regarded as a compound of nepheline and chloride of sodium ; nosean and hauyn as compounds of that mineral with sulphates of soda or lime.*

Decomposition.—The above analyses, particularly those from XII to XVII, represent elæolite that was decomposed to some extent. Blum states that in the pores and drusy cavities of the micaceous, augitic rocks, occurring on the shores of the lake of Laach, there are white incrustations consisting of decomposed nepheline.

CHAPTER XXIX.

WERNERITE AND EPIDOTE.

UNDER the general term wernerite are comprised the minerals called skapolite, bergmannite, spreustein, meionite, ekebergite, nuttallite, schmelzstein, chelmsfordite, pyramidal felspar.

This mineral is considerably acted upon by hydrochloric acid, but is not completely decomposed ; meionite alone is completely decomposed, the silica being separated in the form of powder.

Occurrence.—Wernerite occurs in granite, granular limestone, and in beds of magnetic iron ore. Meionite occurs in the masses ejected from Vesuvius and Somma during the more remote eruptions.

Composition.—About forty-two analyses have been published. The greater number of specimens of wernerite that are still unaltered, correspond with the composition I according to Rammelsberg.† The composition II represents meionite.

				I.	Oxygen.	II.	Oxygen.
Silica ....	....	....	....	52·86	4	42·40	3
Alumina ....	....	....	....	29·40	2	31·44	2
Lime ....	....	....	....	17·74	1	26·16	1
				100·00		100·00	
O. Q.					0·75		1·00

* See ante, p. 135.
† Supplement 5, p. 215.

When perfectly unaltered, wernerite is anhydrous ; but among the great number of analyses that have been made, there are only six which do not indicate the presence of water in the minerals they represent, all the others show the presence of water to the amount of 2·5 per cent.

According to the above, these minerals would consist of silicates of alumina and of lime ; but most of the analyses indicate the presence of alkali, either soda alone or soda with a small proportion of potash, and only six show the absence of alkali. The soda sometimes amounts to 8·7 per cent., the potash to 3·48 per cent. Besides alkalies, these minerals generally contain minute quantities of peroxide of iron and magnesia, the former amounting to as much as 3·8 per cent., the latter to 2·2 per cent. The amount of lime is less in proportion as that of alkalies is greater.

Formation.—It has already been remarked that the occurrence of meionite in the products of the old Vesuvius is not by any means indicative of its formation by fusion.* This meionite contains 3·10 per cent. carbonic acid ; when heated in a glass tube it evolves water and empyreumatic vapour that has an alkaline reaction. This indication of the presence of a nitrogeneous substance cannot be reconciled with the volcanic origin of the mineral, and shows, unquestionably, that it has subsequently been exposed to the action of water. But if water could penetrate the drusy cavities after the mineral had been formed, this might also have taken place previously, and thus the material for the formation of the mineral might have been introduced.

The frequent occurrence of wernerite in granular limestone is considered to be a proof of the igneous origin of this mineral, but it is rather evidence to the contrary, for it will subsequently be shown that granular limestone has been originated from sedimentary limestone, and that the alteration can have been effected only in the wet way. The conditions that are favourable to the formation of wollastonite in granular limestone,† are also favourable to the formation of wernerite in this rock, and for the formation of meionite in the drusy cavities of the granular limestone of Somma.‡ Water dissolves the silicates of alumina and of

* See ante, p. 95.

† See ante, p. 123.

‡ The meionite analyzed by L. Gmelin—Schweigger's Journ. xxv, 36—was found in the drusy cavities of fragments of limestone ejected during former eruptions, and is not very frequent.—Compare, *Prodromo della Mineralogia Vesuviana di Monticelli e di Covelli*. Napoli. 1825, i, 337.

lime existing, though in small proportion, in limestone, and deposits them in the drusy cavities as wernerite. This mineral has likewise been found in the drusy cavities of other rocks, and even in those of argillaceous limestone* and of basalt. It may, however, be laid down as an invariable rule that the occurrence of minerals in drusy cavities of rocks that are either of sedimentary or volcanic origin, is incompatible with the formation of those minerals by fusion.

In the limestone quarries of Pargas there are some remarkable relations between augite and wernerite.† Norderskiöld describes a pseudomorph containing 3·3 per cent. water, and G. Rose informs me that it is wernerite that has been converted into green augite at the surface.

Mica with the form of Wernerite.—Steffens and Hausmann first made known the occurrence of wernerite mixed with mica, and the occurrence of mica with the form of wernerite was described by Haidinger.‡ The wernerite crystals imbedded in quartz were quite unaltered at the middle, while at the ends there were, in the place of the original substance, laminæ of mica intersecting each other in various directions. In this alteration some octahedrons of magnetic iron were separated between the laminæ of mica. Haidinger states that at the interior of the crystals the mica is sometimes mixed with quartz and calc-spar.

Blum§ describes wernerite crystals that are rough and uneven at the surfaces, or covered entirely with greenish, greenish-white, brownish, or grey laminæ of mica. The laminæ of mica are found not only at the surface of the crystals but also at the interior, the entire mass consisting of an aggregate of them, irregularly mixed together. Between the layers of mica there is sometimes a rather compact greenish mass, which at first sight might be mistaken for unaltered wernerite, but it is soft and appears to be an intermediate stage of the conversion of one mineral into the other.

The rough and uneven surfaces of a crystal upon which laminæ of mica occur, is a sure sign that the latter mineral has originated from the former by alteration. If the mica had been formed at the same time as the mineral upon which it is situated, it would have protected this mineral against decomposition, and the surfaces would not have been rough.

* Scheerer.—Jahrbuch für Mineral. &c. 1843, p. 649.

† German edition. i, 518 et seq.

‡ Abhandl. d. k. böhm. Gesells. der Wissen. Prag. 1841, p. 3.

§ Die Pseudomorphosen, p 93, and Nachtrag, i, p. 27.

G. H. Otto Volger * found that a fahl ore crystal, without any trace of copper pyrites, imbedded between iron spar and baryta spar, had smooth and brilliant faces, while that which was covered with copper pyrites had rough faces. There is no reason for doubting the pseudomorphic formation of the copper pyrites from the fahl ore, and this is equally true in the case of the mica situated on the rough faces of wernerite crystals.

Blum has described other specimens of pseudomorphous mica after wernerite, but they do not present any novel features.†

The analyses of mica originating from wernerite, and the explanation of the process of alteration, will be found in chapter XXXVIII.

Epidote will be treated of here on account of its remarkable relation to wernerite. It occurs imbedded and in drusy cavities in gneiss, micaceous schist, hornblende schist, chloritic schist, granite, syenite, diabase, diorite, gabbro, serpentine, and porphyry; in drusy cavities of amygdaloid rocks and in mineral deposits.

Epidote consists essentially of silicate of alumina with silicate of lime—zoisite, or calcareous epidote—or with silicates of lime and of protoxide of iron—pistacite, or calcareo-ferruginous epidote—or with silicates of lime and of protoxides of iron and manganese—manganese epidote. The ratio of the oxygen in the latter bases to that of the alumina and silica is 1 : 2 : 3; so that the oxygen quotient is 1.

Epidote is one of those minerals that become decomposable by means of acids, after they have been ignited, and then the silica separates in a gelatinous state. The absolute weight is not reduced by the ignition more than 1 per cent., but the specific gravity is considerably altered; Rammelsberg‡ found it to be :

Before ignition	....	....	3.403
After ignition	....	....	3.271.

According to Hermann, epidote contains carbonic acid to the amount of 1.13 or 2.73 per cent., and this would indicate that the decomposition of the silicate of lime had commenced.

The occurrence of epidote in so many different rocks is deserving of notice, since it shows that it may be formed wherever the silicates of which it consists are present, whether it be deposited from water in drusy cavities, or formed by the alteration of

* Poggend. Annal., lxxiv, 37.

† Loc. cit.

‡ Supplement 2, p. 48.

other minerals. It is further noticeable, as will be shown subsequently, that the pseudomorphous epidote corresponds, in point of composition, with the other kinds of epidote whose pseudomorphic origin cannot be proved. This correspondence is not always to be detected by analysis, since the incomplete pseudomorphous epidote is more frequent than that in which the alteration is completed. There is, moreover, no ground for the assumption that a mineral which has originated from another by alteration should have a composition different from that which it has when formed directly.

Epidote and albite with the form of wernerite.—Forchhammer* describes a large crystal from Arendal with the form of wernerite, although the substance has been entirely converted into epidote, which is surrounded at the exterior by a minute quantity of albite.† There are cavities between the epidote crystals that are filled with calc-spar. The specific gravity of wernerite is 2.5 or 2.8; that of albite 2.68, and that of epidote 3.2 or 3.5. So that as the new minerals would have a greater density than the wernerite, there must have been a contraction, giving rise to the cavities presented by this pseudomorph.

I found similar wernerite crystals in the Berlin collection of minerals; one of them was completely converted into epidote at one side, and the sharp line of separation was irregular. Another wernerite crystal in the same specimen was green at some parts, owing, probably, to conversion into epidote. A great number of wernerite crystals in another specimen were converted into epidote only at one of their ends. This specimen also contained magnetic iron. Blum‡ has a large columnar crystal of wernerite that has been completely converted into an aggregate of green epidote; it is from the granular limestone of Arendal. Another of the products of the decomposition of this wernerite is mica.§

* Journ. für prakt. Chemie, xxxvi, 403.

† G. Rose showed me a specimen of this kind, which presented indications of the posterior formation of the albite, for it covers the epidote and fills cracks in it.—See ante, p. 195.

‡ Nachtrag, 2, p. 47.

§ The mineral from Sterzing, in the Tyrol, analyzed by Stromeyer as meionite, is associated with pale pinchbeck-colored crystalline mica.—Untersuch, über die Misch. der Mineralkörper, i, 386.—According to Weiss, it is epidote.—Rammelsberg's Handwörterbuch, Supplement 2, p. 138.—However, the similarity of its composition to that of the meionite from Vesuvius, analyzed by Stromeyer, is remarkable.—Loc. cit. p. 378. Perhaps the mineral was a product of the conversion of wernerite or meionite into epidote and mica.

	I.	Oxygen.	II.	III.	IV.
Silica	37.92	3	43.41	46.82	42.37
Alumina	19.21	2.03	...	...	...
Peroxide of iron	15.55		8.68	1.39	8.47
Lime	22.68	1.00	...	...	...
Magnesia	0.25	...	...	...	...
Potash	0.23	...	0.72	0.97	0.60
Soda	0.39	...	3.24	6.88	3.63
Water	2.51	...	...	...	...
	98.74				

I. Pale green epidote with the form of wernerite, from Arendal.*

The crystal taken for analysis was one inch long and half an inch thick; several smaller crystals of the same kind were, like the larger one, attached to a dark green mass in which they were partly imbedded.† This pseudomorphous pistacite corresponds in composition with the specimens of Arendal pistacite analyzed by Kühn, Hermann and Rammelsberg, and has exactly the oxygen quotient of meionite.

II. Wernerite crystals, similar to the prismatic wernerite, intermixed and in part displaced by green epidote substance.‡

III. Prismatic epidote.

IV. Mixture of I and III in equal parts.

As these numbers correspond tolerably well with II, it may be supposed that nearly one-half of the mineral represented by II had been converted into epidote.

G. v. Rath,§ to whom we are indebted for these analyses, remarks that we cannot assume a merely relative increase in the amount of lime to have taken place in the conversion of wernerite into epidote by the removal of other constituents; but that it is rather necessary to suppose an actual introduction of lime to have taken place. The pseudomorphous epidote does not present either cavities or pores; but appears, even by the aid of the magnifying glass, as a perfectly homogeneous mass. Its specific gravity, which was determined with very small fragments, was 3.223. Assuming that the large crystals weighed, while in the state of wernerite,

* Weibye states, that when crystalline pistacite occurs in the calc-spar of the Langseø mine, it is always associated with wernerite.

† According to G. Rose, this mass is augite in a state of alteration.

‡ Unfortunately the estimation of the lime and alumina failed.

§ Poggend. Annal. xc, 307 et seq.

fifteen grammes, it would, when converted into epidote, have weighed 17·925 grm. The wernerite would have contained 2·58 grm. lime, while in the epidote there is 4·06 grm. So that there would be an increase of 1·48 parts lime within the same space where there was previously only 2·58 parts lime.

G. v. Rath was unable to account for the alteration in question because he did not take into account the fact that alkaline silicates are decomposed by sulphate of lime and chloride of calcium.* The experiments with analcime already described† show that this reaction takes place between these substances and the alkaline silicates contained in compound mineral silicates. It is from this fact intelligible that water containing sulphate of lime or chloride of calcium may displace the greater part of the soda from wernerite, and convert the silicate of soda into silicate of lime.

Lastly it has been shown that a partial displacement of alumina may be effected by hydrated peroxide of iron.‡ Therefore it was only requisite that the water should contain, besides the lime salts, carbonate of iron, in order to effect the conversion of wernerite into epidote.

Wernerite with the form of epidote.—Haidinger§ describes a mineral with this form, from Arendal, which consists at the interior of a reddish-grey granular mass, perfectly corresponding with wernerite. It contains water and an empyreumatic substance, and is covered with a white crust.

Epidote with the form of garnet.—In the Berlin collection of minerals there is a brown garnet crystal with some of the faces still brilliant. At the interior it showed signs of conversion into epidote; at one side was unaltered garnet, at the other epidote substance. Another specimen from Eck in Norway consisted of a mixture of garnet and epidote.

Alteration pseudomorphs of this kind are described by Blum|| as occurring in a drusy cavity of the garnet rock at the "saalbänder" of the granular limestone of Auerbach. The garnet crystals presented different stages of alteration, which appears to have commenced at the surface, the brownish-red garnet becoming covered with a thin blackish-green crust of epidote. Some crystals are almost surrounded by epidote substance, so that

* English edition, i. 11.

† See ante, p. 142.

‡ See ante, p. 76.

§ Abhandl. der böhm. Ges. der Wissensch. im Prag. 1841, p. 4.

|| Nachtrag, 2, p. 11.

only a few specks of garnet are perceptible. The sharpness of the crystals disappears gradually, and finally there remains a porous mass of epidote presenting indistinct outlines of the original form.

An analysis of the brown epidote of Auerbach was made by Wandel,* according to which it consists of:

Silica	....	....	....	41.59
Alumina	....	....	....	22.04
Peroxide of iron	....	....	....	16.04
Lime	....	....	....	18.68
Magnesia	....	....	....	3.21
				<hr/>
				101.56

This corresponds somewhat with the above analyses of epidote with the form of wernerite. But as it is not known whether the epidote with the form of garnet has the same composition as the epidote of Auerbach; and further, as the composition of the garnet, from which the former originates, is unknown, but little can be said as to the process of alteration.

The proportion of silica to alumina is nearly the same in epidote and in garnet, so that the alteration would appear to be confined to the other bases, and the porous state of the pseudomorphs would indicate partial removal of these bases.†

Epidote appears like wernerite to be capable of conversion into mica. Blum ‡ describes epidote crystals from a quartz dyke in gneiss, at Athol, Massachusetts, which are here and there enveloped by pinchbeck-colored or brownish-green mica, which sometimes penetrates into the mass of the crystals. Where the crystals are in contact and are not surrounded by quartz, the mica is abundant and they consist of a mixture of this with epidote.

Steatite with the form of wernerite.—Fowler § found this pseudomorph in the granular limestone near Newton, New Jersey. Blum || found it in a specimen from the magnetic iron deposits of Arendal. It consists of several attached crystals two or three inches long presenting the form of wernerite, but entirely converted into steatite. At one side the pseudomorphs are attached to felspar between which calc-spar is situated in many places. The alteration commences at the surface and extends inwards.¶

* Rammelsberg's Handwörterbuch. Supplement 5, p. 105.

† This process of alteration will become clear only when the original garnet and the epidote derived from it are analyzed. The specimen in the Berlin collection would be well adapted to this purpose.

‡ Nachtrag, 1, p. 30.

§ Silliman's American Journ. 1832, p. 320.

|| Die Pseudomorphosen, p. 134, and Nachtrag, i, p. 75.

¶ See Chapter xli.

*Wernerite with the form of Vesuvian.**

Sillem states, that at Eg in Norway, pseudomorphs occur consisting of a mixture of vesuvian with a smaller quantity of garnet. They present the form of vesuvian, are tolerably large, rough and drusy at the surfaces, with small crystals of wernerite at some parts.†

Wernerite appears also to be capable of other alterations. Scheerer‡ found in a small island near Lövöen, Norway, reddish wernerite presenting distinctly the crystal form of quartz. The structure likewise indicated that it was pseudomorphous after quartz, and if this is the case, their formation is very remarkable for they are found attached to felspar that is perfectly fresh and unaltered.

Decomposition of wernerite without formation of any definite mineral.—Wernerite very generally effervesces with acids, even those specimens which do not present any external indications of alteration. A specimen in my collection, from Arendal, that is covered with a number of small silver white laminæ of mica, effervesces at many parts when immersed in acid, small bubbles of gas being evolved from the interior of the crystals. The carbonate of lime originating from the decomposition of the silicate of lime, does not, therefore, cover the surface, but is buried in small fissures and cavities within the crystal.

Weibye § describes fractured wernerite crystals, the interstices of which are filled with calc-spar. I saw in the Berlin collection of minerals a large wernerite crystal that was broken in two places, and the interstices filled with quartz. Both the calc-spar and quartz may have been deposited by water flowing through these interstices, and the carbonate of lime may have originated from the wernerite itself by decomposition subsequent to the fracture of the crystal.

At Krageroe in Norway, specular iron is found in small fissures and cracks in the wernerite crystals.

The analyses of decomposed wernerite by E. Th. Wolff,|| Hermann,¶ and v. Rath** have contributed to the elucidation of the processes of decomposition to which wernerite is liable.

* See Chapter xxxiv.

† See Blum.—Nachtrag, 2, p. 46.

‡ Jahrb. für Mineral. &c. 1843, p. 642.

§ Archiv. für Mineral, &c. xxii, 465 et seq.

|| De compositione fossilium Ekebergites, scapotithi, et meionites. Berolini, 1843.

¶ Journ für practk. Chemie, liv, 420.

** Loc. cit.

The following analyses are by Wolff,

	I.	II.	III.
Silica	61.64	61.50	92.71
Alumina	25.72	25.35	} 7.29
Peroxide of iron	1.04	1.50	
Oxide of manganese ....	...	1.50	
Lime	2.98	3.00	
Magnesia ...	...	0.75	
Potash	} not estimated	} 5.00	
Soda ...			
Loss by ignition	1.86		
	93.24	98.60	100.00

I. Large yellowish-grey dull wernerite crystals, from Arendal.

II. Red wernerite from Sjösa in Sweden.

III. Thin greyish crystals imbedded in calc-spar, from Pargas.

The minerals represented by I and II, appear to have been decomposed by the action of carbonic acid alone, to such a degree that the greater part of the lime and probably a portion of the alkalies have been removed as carbonates, while the silica of the decomposed silicates remained, and that, therefore, there has been a considerable relative increase of this substance.

The almost entire elimination of the bases from III would indicate a very considerable diminution of the volume unless silica had been introduced. The description of the mineral, however, does not afford any information on this point.

Analyses by Hermann.

	IV.	V.	VI.	VII.	VIII.
Silica	57.60	54.92	55.29	53.11	51.81
Alumina	24.69	31.14	28.87	27.97	32.45
Peroxide of iron ....	...	...	...	2.84	...
Protoxide of iron	1.05	0.13	0.31	...	2.53
Protoxide of manganese	0.15	0.15	0.25	0.27	0.28
Lime	6.19	10.27	7.51	9.73	9.76
Magnesia	0.21	0.83	...	0.39	...
Potash	1.31	1.00	0.55	0.86	0.79
Soda	8.90	1.56	7.22	4.83	2.38
Water ....	...	0.80	0.66	...	0.30
	100.00	100.80	100.63	100.00	100.30
Calc-spar	3.18	3.74	1.91	3.82	5.17

IV. White wernerite from Gouverneur, New York, intimately mixed with calc-spar.

V. Red wernerite from the same place.

VI. White wernerite from Gulsjö.

VII. Eckebergite from Hesselkulla.

VIII. Nuttallite from Diava, New York.

As the amount of silica in these five specimens of wernerite, exceeds the normal amount, it may be inferred that decomposition by carbonic acid has already taken place. This is also indicated by the presence of carbonate of lime.

Analyses by v. Rath,

	IX.	X.	XI.	XII.	XIII.
Silica	49.5	49.99	57.20	59.74	29.52
Alumina	27.5	23.01	26.35	16.20	15.77
Peroxide of iron ....	...	1.64	1.88	7.90	19.14
Lime	15.0	3.35	3.84	2.15	9.02
Magnesia ....	...	1.73	1.98	4.02	8.50
Potash ....	...	7.09	8.34	4.42	0.37
Soda	8.0	0.35	0.41	4.31	0.58
Water ....	...	4.23	...	1.83	10.89
Carbonate of lime ....	...	7.80	...	...	4.62
	100.0	99.19	100.00	100.17	98.41

IX. Unaltered wernerite.

X. Yellow wernerite from Bolton, Massachusetts.

The physical characters of this mineral indicate decomposition.

XI. The same after deducting the carbonate of lime and water.

XII. Red wernerite, from Arendal.

The physical characters distinctly indicate far advanced decomposition; the crystals are often several inches long, and are associated with hornblende in the deposits of magnetic iron ore.*

XIII. Black wernerite from Arendal.

This mineral was so soft that it could be penetrated to some depth by a knife; it did not present any trace of cleavage.†

* Weibye states that the red wernerite from one of the mines appears quite disintegrated. It is worthy of notice, that the interstices of the broken, green wernerite crystals from Krageroe are filled with compact red wernerite, for this distinctly shows that red wernerite is a product of the decomposition of the green wernerite, and that it may be removed by water. The green crystals at this place are always bent or fractured, sometimes both.

† Weibye states that the black colour of this wernerite arises from decomposition; the mineral is found only in the rubbish of a mine abandoned since 1810.

As carbonic acid decomposes silicate of lime readily,* and as carbonate of potash decomposes silicate of soda,† the presence of these two substances in water would be sufficient to effect the decomposition of this mineral with separation of lime as carbonate and conversion of the silicate of soda into silicate of potash.

Carbonic acid is always present in the water of springs; carbonate of potash is always present in water that penetrates felspathic rocks, unless earthy salts such as sulphates of lime or magnesia effect its decomposition. In X and XIII there is still some of the carbonate of lime, the other portion was removed, together with carbonate of soda, by water, and the whole of the carbonate of lime has been removed from XII. The displacement of the soda is almost complete in X, and in XII it is about half way advanced.

In the decomposition of silicate of lime, silica is separated, and the relative increase of this substance in XI and XII shows that it remained. In XI there is only a minute decrease of alumina, but in XII it is considerable, and in the latter mineral there is a considerable increase of peroxide of iron while in the former mineral it is small. Therefore the partial displacement of alumina by peroxide of iron is unmistakeable, and it has already been shown how this takes place.‡

G. v. Rath raises the question why the wernerite XI, which in composition greatly resembles the varieties of mica rich in silica has not actually been converted into mica. There are many instances in which minerals have a composition almost identical with that of mica and are nevertheless very different from it in other respects.§ Moreover mica with 57·20 per cent. silica is rare, and lime, which does not enter into the composition of mica, amounts in XI to 3·84 per cent.

The process of decomposition in the case of XIII has been entirely different from that which took place in X and XII. A large portion of the silica as well as of the potash and soda have been separated from this mineral, while the silicate of lime remained unaltered; so that carbonic acid must have been less concerned in this decomposition than in that by which X and XII were produced. The displacement of alumina by peroxide of iron was evidently the predominating action; for the oxide of iron introduced amounts to more than the alumina removed, and the amount of

* English edition, i, 2.

† See ante, p. 65, No. 38.

‡ See ante, p. 76.

§ See Chapter xxxi.

these substances in the mineral is greater than that of alumina in unaltered wernerite.* The considerable increase of magnesia, which appears to have been introduced into X and XII, though in smaller quantity, admits of the inference that there has been a decomposition of the alkaline silicates, and probably, in a less degree, of silicate of lime, by magnesian salts.† If the alkaline silicates have been converted into silicate of magnesia by means of sulphate of magnesia or chloride of magnesium, there could not have been any carbonate of potash in the water which effected this alteration, so that in this case there would not have been any conversion of the silicate of soda into silicate of potash, but the soda would have been removed as sulphate or as chloride of sodium.

Although there is but slender ground for any opinion as to the nature of the decomposition which has given rise to the formation of the mineral represented by XIII, there is the more reason to wish for opportunities of submitting the products of such modes of alteration to chemical analysis. Perhaps it would then be possible to obtain some clue to their history.

It is, however, at least certain that the decomposition was of such a nature in XIII as would tend to the formation of ripidolite. Comparing XIII with XIV and XV—flaky chlorite from the granite of the Dauphine analyzed by Marignac—and with VIII—laminar chlorite from Gummuchdagh, in Asia Minor, analyzed by G. Smith—it will be seen that by the perfect decomposition of the silicates of lime and of the alkalies in XIII, by means of magnesian salts, a product might be formed having a composition similar to that of XIV, XV and XVI. The amount of water in these specimens of ripidolite agrees perfectly with that in XIII.

				XIV.	XV.	XVI.
Silica	....	....	....	26·88	27·14	27·20
Alumina	....	....	....	17·52	19·19	18·62
Protoxide of iron	....	....	....	29·76	24·76	23·21
Magnesia	....	....	....	13·84	16·78	17·64
Water	....	....	....	11·33	11·50	10·61
				99·33	99·37	97·28

* In the decomposition of wernerite, peroxide of iron is always introduced in considerable quantity.
† See ante, pp. 66 and 67, Nos. 40 and 41.

As wernerite is capable of conversion into mica and steatite, there is no reason why it may not likewise be capable of conversion into chlorite,* or even into serpentine.

	XVII.	XVIII.	XIX.	XX.
Silica	38.00	46.39	48.32	55.47
Alumina	24.10	29.09	28.44	32.65
Protoxide of iron	4.82	2.04	1.40	1.61
Protoxide of manganese	0.78	...	...	...
Lime	22.64	5.13	6.88	7.90
Magnesia	2.80	1.97	2.07	2.37
Potash ....	...	trace	trace	trace
Water	6.95	1.80	1.80	...
Carbonate of lime ....	...	10.72	10.72	...
	100.09	97.14	99.63	100.00

XVII. Atheriasite from Arendal, analyzed by Berlin†.

Hausmann‡ states that the crystal form of this mineral is identical with that of wernerite.

XVIII and XIX. Greenish mineral with the structure of wernerite, from Franklin, New Jersey; analyzed by Brewer.§

XX. The same after deducting the water and carbonic acid.

The identity of the crystal form of XVII with that of wernerite is a sufficient ground for regarding this mineral as a pseudomorph. The composition is unmistakably similar to that of epidote with the form of wernerite, || except that in the case of XVII the decomposition does not appear to have advanced so far as in the pseudomorphous epidote. As the remarks previously made in reference to the pseudomorphic epidote are likewise applicable to the alteration in the case of XVII, it appears that the displacement of alumina by peroxide of iron has not advanced so far as in the case of the epidote. The total amount of both bases in XVII is 28.92 per cent., while in pseudomorphous epidote it is 34.76 per cent., so that the quantity of peroxide of iron introduced would appear to be greater than that of the alumina removed. The same character is presented by XIII.

* According to Weibye, there is a kind of wernerite occurring at Arendal, which presents a disintegrated appearance, owing to the presence of a great number of imbedded mica or chlorite laminæ.

† Poggendorff's Annal. lxxix, 302.

‡ Ibid. lxxxi, 567.

§ Dana's Mineralogy. Ed. 4, ii, 203.

|| See ante, p. 243. I.

On the other hand, the total absence of alkalies from XVII is striking, since traces are still present in the pseudomorphous epidote.

There is, as Rammelsberg has pointed out, some similarity between XVIII, XIX and X; this is more evident from a comparison of XX with XI. There is, however, the difference that in XX the alkaline silicates have been entirely decomposed, while in XI the silicate of soda of wernerite has been converted into silicate of potash, and further that there has been less silicate of lime decomposed in XX than in IX; so that in the former instance the decomposition was principally confined to the alkaline silicates, and in the latter these silicates were not acted upon, but merely the silicate of lime was decomposed. But as there appear to be varieties of wernerite that are quite destitute of alkalies, it is possible that the mineral represented by XX has originated from wernerite of this kind.

There is no mineral that is known to be capable of undergoing more numerous and diverse alterations than wernerite. However, I am of opinion that other minerals would present the same features if there had been as extended an investigation of the products of their alteration as has been made of those originating from wernerite. In the water of springs we find the greatest diversity both in the qualitative and quantitative relations of the substances in solution; and, perhaps, it would not be too much to say that the processes of alteration that any mineral is capable of undergoing is equally varied, and that the particular kind of decomposition or alteration that takes place in any instance will depend upon the nature of the water by which it may be effected.

CHAPTER XXX.

TOURMALINE.

TOURMALINE generally contains but little hygroscopic water, but when the mineral is ignited fluoride of silicum is evolved. According to v. Kobell it is not acted upon by hydrochloric acid, when powdered; and is but imperfectly decomposed by sulphuric acid. The powder of the melted mineral is perfectly decomposed by long digestion with concentrated sulphuric acid. Rammelsberg found that after intense ignition it is perfectly decomposed by hydrofluoric acid.

Occurrence.—The black tourmaline has, in a geological point of view, the greatest importance, since it is the most frequent variety. It is an essential ingredient of tourmaline schist and of topaz rock; it occurs in granite as a substitute of mica, in gneiss, micaceous-, chloritic- and talcose-schist, in hornblende rock, granular limestone, in deposits of magnetic iron ore and on metalliferous lodes.

Formation.—The occurrence of this mineral upon metalliferous lodes together with substances that are decomposed by heat, such as steatite, pyrophyllite with 5·6 per cent. water, bitter spar, iron pyrites, etc.; upon lodes in clay slate, in Cornwall, between Bidschow and Turnau in Bohemia; in calc-spar at Newten, U. S., and in the Hornfels at the Harz, where it is sometimes distinctly developed, and from the dark colour of the rock may be recognized as an intimate admixture, as well as its occurrence in drusy cavities of granite, in topaz rock, associated with quartz or with topaz and steinmark, as at the schneckenstein in Saxony, in topaz crystals, in the dykes containing topaz in the Ilmen mountains;* and upon fissures in granite and dolomite, furnishes evidence that leaves no doubt of its having been formed in the wet way.

The tourmaline schist in Saxony consists, according to Freiesleben,† of alternate white and black layers, the former being very fine granular quartz, the latter fine-grained tourmaline, generally mixed with some quartz, and probably with some chlorite. The quartz layers contain grey or reddish mica, the

* G. Rose.—Reise, etc. ii, 82.

† Geognost Arbeiten, vi, 1 et seq., and Magazin für die Oryktographie von Sachsen, i, 105 et seq.

tourmaline layers black mica. These two layers are generally quite distinct, but their outline is generally undulating and irregular. The tourmaline schist appears either as a product of the alteration of the schistose rocks at the points of contact with granite, or it forms dykes in those rocks.*

Naumann directs attention to the great similarity between these conditions and those in Cornwall, described by Forbes, Carne, Boase and Hawkins.†

I am disposed to regard the formation of layers parallel‡ to the saalbands, such as are met with so distinctly in tourmaline dykes as decisively indicative of formation in the wet way. It is indeed a stratification resulting from the deposition of substances from water flowing slowly down the sides of a fissure.

As tourmaline never occurs in volcanic rocks, there is no single fact that would indicate its formation by fusion, and we must, therefore, regard such a mode of formation as impossible.

The fact that the tourmaline crystals are sometimes fractured and cemented together again by quartz is well known. In two fine specimens of black tourmaline, one from the quartz at Gielhof in Moravia, and another from St. Gotthard, that had been fractured in eight places, I observed the following characters. The force by which the first tourmaline crystal was broken acted in the direction of two rectangular planes, so that not only the lateral edges but also the exposed upper face formed an obtuse angle. In the second tourmaline crystal each fragment was in a somewhat different position. In a specimen from Sterzing in the Tyrol, the tourmaline crystals lying in quartz and granite were broken and the surfaces of fracture were about a line apart. In another specimen from the granite of Kasernen in Moravia small crystals of tourmaline were broken in two and the space between the surfaces of fracture filled with felspar or with quartz. Here the felspar must have been a product of infiltration, as is not unfrequently the case. The tourmaline crystals must have been formed before the quartz, which presents impressions of the tourmaline crystals and fills cracks in them, so that supposing the tourmaline to have been formed by fusion, the quartz must have been in a very liquid state.

* In the mineral collections at Freiberg I have seen specimens of tourmaline rock presenting the most distinct indications of formation in the wet way. Silica formed the cement.

† Boase.—Trans. of the Geol. Soc. of Cornwall, iv, 242.

‡ German edition, ii, 446 et seq.—I have shown that the formation of layers parallel to the sides of dykes is quite inconsistent with the opinion that the mass filling a dyke has risen from beneath in a melted state.

With regard to the igneous origin of tourmaline and quartz, it must, however, be remembered that the extremely elevated temperature that would be required to render quartz liquid, is altogether incompatible with the preservation of the tourmaline which melts at much lower temperature than quartz. Whether it is supposed that tourmaline and quartz separated from a melted mass, or that tourmaline crystals were enveloped by melted quartz; in both cases the dissimilarity of their melting points together with the mode of their association as minerals, furnishes decisive evidence against the possibility of their formation by fusion. This is particularly evident where quartz is found filling minute cracks in tourmaline crystals, and where small tourmaline crystals sometimes as thin as a needle are imbedded in large masses of quartz.

The origin of broken tourmaline crystals cemented together by quartz may be accounted for without difficulty by the assumption that the quartz has been deposited from solution in water. When the crystal was cemented by quartz at one side, it must, in consequence of the hardening of this substance, have been bent and lastly broken; and if water containing silica in solution continued to be supplied, a further quantity of quartz would be deposited between the fragments, however narrow the space might be, for the silica would be conveyed wherever the water could penetrate.

The fracture of tourmaline crystals may be owing either to the contraction of the quartz deposited upon them, during its solidification, or to the pressure of superincumbent masses. In the latter case, however, the quartz would likewise have been fractured, and although it may be supposed that the fractured surfaces of the quartz would be cemented together by quartz substance, so as not to be recognizable, still there is much difficulty in supposing that a crystal of tourmaline would be broken by pressure into eight short pieces without further fracture.

The powerful contraction of some substances, soluble in water, when they are separated in a solid state by evaporation is illustrated by albumen and gelatine. The layer formed upon glass or porcelain cracks during solidification, and is detached, removing with it portions of the glass or porcelain. This circumstance indicates a very intense adhesion, greater than the cohesion of glass or porcelain, and is not at all to be compared with the small force requisite for breaking tourmaline crystals.

Tourmaline frequently occurs imbedded in quartz, but the crystals are never perfectly developed; however, it occurs in

regular crystals associated with quartz in drusy cavities.* In both cases the tourmaline is of anterior formation.

The very different colours of tourmaline crystals—white, red, blue, green, yellow, brown, and black, is particularly remarkable because the same crystal is sometimes variously colored, or a crystal of one colour is imbedded in one of another colour. The finest specimens of this kind are from St. Pietro in Elba. Some of them are rose-colored, with the ends colorless and separated from the colored portion by a small reddish layer; others are black at the lower end, yellowish-green in the middle and rose colored at the upper end, the black and green being in most instances distinctly separated, while the green and rose-colored portions are frequently blended. Other crystals again are rose-colored at the lower end, olive-green higher up, and covered at the upper end with a thin distinctly marked black layer; lastly there are crystals that are blackish-green at the lower end, transparent higher up and covered at the upper end in a distinctly marked black layer. At Chesterfield and Goshen, U. S., red crystals of tourmaline are frequently imbedded in green crystals and sometimes there is a small layer of steatite between the two. Very often several red crystals are imbedded in a green crystal; green crystals are likewise imbedded in blue ones, and blue crystals in green ones.†

In the drusy cavities of granite that forms dykes traversing the serpentine near Schaitansk, there are small, transparent crystals, broken at one end and pale olive-green or liver-green, and at the crystalline end deep red. Others are red at the broken end, green at the other, with a very thin layer at the extremity, which is red. Some larger crystals are violet-colored and transparent at the upper end, but darker, almost black and opaque at the other end. The crystals often contain others of a different colour, most frequently brown, or dark colored crystals imbedded in red tourmaline.‡

The colour of tourmaline crystals has no connection with their perfect or fractured state. The dissimilar colour of the same crystal at different parts, and the presence of a crystal of one colour imbedded in a crystal of another colour, unquestionably

* Breithaupt.—Paragenesis, p. 56.

† G. Leonhard.—Handwörterbuch, pp. 515 and 517.

‡ G. Rose.—Reise, etc., i, 461. Some of the crystals contain globular masses that may be detached, and which do not possess the cleavage of the tourmaline; they have a less specific gravity, and are not susceptible of electrical excitation.

indicates a very gradual formation and sudden changes in the material from which they were formed. The red tourmaline is free from iron, but contains a somewhat considerable quantity of manganese, to which probably the red colour is owing.

The brown and red tourmaline becomes colorless before the blow-pipe, the green tourmaline becomes either colorless, greyish-yellow, or brown. Most of the black, brownish-black, and bluish-black kinds become greenish-white, brownish-yellow, grey, greyish-brown, brown, brownish-red or black. Generally speaking, it is those kinds containing much iron that present these alterations of colour. One specimen of black tourmaline, from the Zillerthal, and another from Godhaab in Greenland become colorless before the blow-pipe, and they are among those that contain the least iron. Perhaps the colour of those kinds of tourmaline which become colorless before the blow-pipe is owing to the presence of organic substance.

Composition.—The earlier analyses of tourmaline show great differences in its composition. Blum remarks that this would appear to be owing, in many instances, to the tendency to alteration. If, therefore, the form were retained from the commencement of the alteration to its completion, the variation in composition might be indefinite.

Rammelsberg* has published thirty analyses of tourmaline, in which he paid especial attention to the estimation of boracic acid, and the relative amounts of the two oxides of iron. It follows from these thirty analyses, that the average proportion of the oxygen in the boracic acid, to that in the silica is 1 : 3·5, and although the amount of silica in the individual specimens of tourmaline is not uniformly the same, this proportion is closely approximated to in all but four of the minerals analyzed. Rammelsberg is of opinion that this circumstance indicates the substitution of these acids by each other.

The sesquioxide bases in tourmaline are, alumina, sesquioxides of iron and manganese, the first always preponderating largely. The monoxide bases are protoxides of iron and manganese, magnesia, lime, and alkalies; soda preponderating over potash, although the latter base is always present. Lithia is found only in the green and red tourmaline.

From the comparison of the proportions of oxygen in the monoxide bases, the sesquioxide bases, the silica and the boracic acid, it appears that these proportions are not uniform in all kinds

* Poggend. Annal. lxxx, 449 et. seq., and lxxxi, i, et seq.

of tourmaline. Rammelsberg arranges the different kinds of tourmaline into five groups, according to the nature of these proportions.

	I.	II.	III.	IV.	V.
Monoxide bases	1	1	1	1	1
Sesquioxide bases	3	4	6	9	12
Silica and boracic acid	5	6	8	12	15
Oxygen Quotients	0·8	0·833	0·875	0·833	0·866

I. Yellow and brown tourmaline, containing very little iron, but the maximum amount of magnesia.

II. Black tourmaline, containing a medium amount both of iron and of magnesia.

III. Blackest tourmaline, containing the largest amount of iron and the smallest amount of magnesia.

IV. This group comprises black, or rather violet tourmaline, one specimen of blue, and all the green tourmaline; almost all containing lithia, together with iron and manganese.

V. Red tourmaline, containing lithia, and free from iron.

The following table contains the results of Rammelsberg's analyses of a specimen of tourmaline belonging to each group:—

GROUP.	I.	II a.	II b.	III.	IV.	V.
Fluorine	2·28	1·78	1·95	1·64	2·00	2·58
Phosphoric acid	trace	trace	..	0·12	..	0·27
Silica	38·85	37·50	36·55	36·51	38·47	38·33
Boracic acid	8·25	7·94	4·87	7·62	7·69	9·00
Alumina	31·32	30·87	32·46	32·92	40·93	43·15
Peroxide of iron	1·27	8·31	11·08	8·13	3·08	..
Protoxide of iron ....	..	1·06	0·50	9·51	..	..
Protoxide of manganese ..	..	..	..	0·11	1·55	1·12
Magnesia	14·89	8·60	8·51	0·78	1·21	1·02
Lime	1·60	1·61	1·80	0·72	0·88	..
Soda	1·28	1·60	2·28	1·36	2·36	2·60
Potash	0·26	0·73		0·58	0·36	0·68
Lithia ....	..	..		..	1·47	1·17
	100·00	100·00	100·00	100·00	100·00	99·92

I. Brown tourmaline from Gouverneur, New York.
This contains the largest amount of magnesia.

II *a*. Black tourmaline in quartz, from Haddam, Connecticut.

II *b*. Large crystal of black tourmaline, associated with chrysoberyl in a granite dyke at the same place.

This mineral appeared to be somewhat decomposed. The faces were mostly smooth and bright, but presented cavities filled with iron ochre, and more particularly laminæ of mica, which were likewise abundant at the interior, and when separated, the surfaces appeared covered with red oxide of iron. The yellow quartz associated with this tourmaline was darker coloured near the tourmaline crystals than elsewhere. Talc or chlorite was situated between them.

III. Black tourmaline from the Sonnenberg near Andreasberg in the Hartz.

This mineral occurs in a granite, with numerous drusy cavities, the felspar of which is much decomposed. The substance of the tourmaline was very hard and fresh; it was free from any perceptible admixture.

IV. Green tourmaline from Paris in Maine, U. S.

This mineral is imbedded in red tourmaline and presents sharp outlines.*

V. Red tourmaline, which occurs together with the previous mineral, and in greater quantity.†

The last two minerals differ very little in composition; the greatest difference being the absence of iron from V, while IV contains iron, the amount of manganese being nearly the same in both. It is very probable that the difference of colour is owing to the different amount of these oxides.

Rammelsberg infers, from the numerous analyses that he has made, that there are varieties of tourmaline that have distinctly different composition. If their crystal form is the same, it would follow that similarity of form is not necessarily attended by analogy in composition, as in ordinary isomorphism.‡ Rammelsberg regards tourmaline as a compound of either bisilicates and borates, or trisilicates and borates of monoxide bases with monosilicates and borates of the sesquioxides, in the proportion of 1 atom of the former to 3·4 or 6 atoms of the latter, so that he was unable to include all kinds of tourmaline under the same formula.

When on the contrary, the oxygen quotients of tourmaline

* According to Dana, red tourmaline occurs at this place imbedded in green tourmaline, or the crystals are red at one end and green at the other.

† Probably the same mineral as that in which the green tourmaline is imbedded.

‡ See ante, p. 85.

are compared, the differences that present themselves are very small; and it may be assumed that they arise chiefly from defective estimation of the oxides of iron and of manganese. Rammelsberg remarks that the estimation of the relative amount of protoxide and of peroxide of iron is exceedingly difficult, and that it is impossible to effect it with that degree of accuracy that is desirable; and this is also the case, though in a less degree, with the oxides of manganese even when they are not associated with iron. These differences may be in part owing to the defective estimation of boracic acid, which Rammelsberg was almost always obliged to estimate from the deficiency. Lastly, he does not overlook the difficulty there is in determining whether the tourmaline selected for analysis is in a perfectly normal and unaltered condition. The mineral may present the form, lustre, and even cleavage, of tourmaline, and nevertheless have undergone considerable chemical alteration, recognizable only by analysis; the greatest attention should, therefore, be paid to the hardness, interior structure of the mass, the amount of water, etc., for the purpose of recognizing any decomposition.

It is impossible to overlook the uniformity in the oxygen quotients of tourmaline; the mean value is 0.841, and this may be taken as the general exponent of their composition. There is a perfect correspondence with the results of analysis when the limits of variation in the oxygen quotient are taken as 0.8 and 0.875. The proportion of the oxygen of the bases as a whole, to that of the silica and boracic acid is, therefore, nearly constant; and this would appear to show that the distinction drawn between strong and weak bases is merely arbitrary.

Rammelsberg remarks that the oxygen of all the bases and of the boracic acid bears the same proportion to that of the silica, as 4:3, the greatest individual deviations being as 4.3:3 and 3.8:3. But as the proportion of oxygen in the silica to that in the boracic acid is tolerably constant, it is evident, that constant relations will be obtained whether the oxygen of the boracic acid is added to that of the bases or to that of the silica as I have done.

Tourmaline is characterized by peculiar optical and electrical properties, thus in the plane of the principal axis it does not transmit polarized light, or at most, transmits it very imperfectly, and when rubbed or warmed it acquires electrical polarity. Rammelsberg* made some observations as to the optical properties of tourmaline with a view to ascertain whether there were any differences

* Blum. loc. cit. p. 36.

corresponding to the five groups into which he divides tourmaline. Breithaupt found that the longer fragments of the crystals associated with quartz were more firmly attached at the positive pole than at the negative pole.

*Mica with the form of tourmaline.**—Tourmaline crystals, particularly the black variety, are not unfrequently covered with laminæ of mica; sometimes they present cracks parallel to the transverse axes, and filled with mica. Ficinus† gives a full description of a pseudomorph of this kind. In the granite of Kleinchursdorf, tourmaline crystals, covered with silver white scales of mica are frequent; sometimes the crystal consists chiefly of mica. The most remarkable pseudomorphs are those in which the exterior has all the characters of tourmaline, while the interior consists of silver-white and grey mica and sometimes a nucleus of tourmaline. Other of these crystals are hollow and lined with small six-sided laminæ of mica.

Blum observed an instance of the conversion of tourmaline into mica in the granite near Heidelberg, and in that of the Hörlberg in Bavaria. Many of the tourmaline crystals occurring at the latter place present the colour, hardness, or lustre proper to this mineral, only where they are entirely unaltered; and where alteration has commenced they are brownish, without lustre, and very soft, so that these crystals have a spotted appearance at the surface. I have found black tourmaline crystals mixed with mica inside.

At Grafton, in New Hampshire, black tourmaline occurs between large laminæ of mica.‡ The black mica in the tourmaline beds§ may probably, like those just mentioned, be products of the alteration of tourmaline. At least the difference between its colour and that of the mica in the quartz layers would appear to indicate that they were of different origin.

The red tourmaline of Mount Hradisko near Rozena in Moravia, has been shown by Blum to be subject to conversion into lithia mica; the phenomena that it presents are quite similar to those of the alteration of black tourmaline.|| This red tourmaline occurs in granite, generally imbedded in lepidolite or quartz. In the latter case the crystals may often be separated from the

* Blum.—Loc. cit. p. 94.

† Schriften der Gesellschaft für Mineral, zu Dresden, 1849, ii, 212.

‡ Breithaupt, loc. cit., p. 707.

§ See ante, p. 254.

|| In the Edinburgh Museum of Natural History there is a pseudomorph of this kind.

quartz by a blow, leaving an impression of their form, lined with a white substance resembling mica. A similar substance sometimes covers one end of a crystal, while the other end presents its natural appearance. The peach-red or blood-red colour of these crystals passes into yellowish-white or greenish-white, they become dull and soft. The outer portion frequently presents the colour, hardness and lustre of tourmaline, while the interior consists of whitish, yellowish, or greenish mica. The crystals have generally a great number of transverse cracks, containing laminæ of mica, and sometimes they consist entirely of mica, or of a mixture of mica and tourmaline. The mica is scarcely ever pure but generally contains some tourmaline particles, and it very rarely presents the red colour of lepidolite.

A fragment of red tourmaline from St. Pietro in Elba, presents the alteration more distinctly. The faces of the tourmaline are irregular and covered with laminæ of white mica with a greenish tinge in places. When the fragment was broken, the cleavage surfaces were so covered with laminæ of mica that the red tourmaline underneath could not be seen. The tourmaline substance was quite destitute of lustre, earthy and could be scraped with a knife. This specimen shows distinctly that the alteration commenced at the outer surfaces and at the cleavage planes where water had penetrated.

The Berlin collection of minerals contains a red tourmaline crystal, with green stripes running lengthways. The felspar near it is partially converted into kaolin. The quartz is covered with an earthy crust, originating from tourmaline that has been entirely decomposed. The laminæ of mica are situated almost entirely upon the tourmaline, and are sometimes very numerous; they are very seldom upon the felspar, and where this is the case a very small fragment of red tourmaline may often be recognized.

Rammelsberg mentions that among the thirty specimens of tourmaline analyzed by him, there were twelve which had cavities at the surfaces containing laminæ of mica, and that sometimes the mica was imbedded in the tourmaline. It is deserving of notice that only the black, brown, and red tourmaline contain mica, and that the green tourmaline does not. Red tourmaline crystals from Elba, that were turbid and brittle, were also covered with laminæ of mica, and sometimes consisted in part of mica. Rammelsberg, in examining the view held by Blum and myself, as to the conversion of tourmaline into mica,* found that mica is always

* German edition, ii, 438, et. seq.

present where the tourmaline is soft, the faces rough and drusy, and when the lustre and transparency is gone, or where it presents indications of alteration.

The chemical features of the conversion of tourmaline into mica will be treated of in chapter xxxviii. The following facts will show that this alteration is one that has a geological importance.

Breithaupt * observes that there are some kinds of granite in which the spaces that contained tourmaline crystals are now filled with mica, generally lepidolite. In other parts these spaces are only partially filled with mica, and in some there is only tourmaline. Masses of black tourmaline occur in the granite at Dekalb, in New York, that have a compact and columnar structure, and are covered with white mica which penetrates between the columns and separates them. At some parts the mica extends into the tourmaline, and is mixed with it; so that it is evident that the mica has been formed from the tourmaline.†

Chlorite with the form of tourmaline.—G. Rose ‡ describes a chloritic schist near Kassoibrod, in which there occur black tourmaline crystals, the ends of which consist of scaly chlorite, and have the appearance of being imperfect pseudomorphs. Similar columnar crystals consisting wholly of chlorite occur more frequently, and some pieces of the rock appear to consist solely of columnar masses grouped together round a centre. Another chloritic schist in this neighbourhood was found to present similar characters; it consists of a granular, scaly mixture of leek-green chlorite, with pinchbeck-colored mica, with here and there long straight cylinders consisting of talc laminae, arranged round the longitudinal axis. Neither tourmaline nor any other minerals occur in this schist, so that there is greater difficulty in accounting for the origin of these cylindrical masses of talc. G. Rose § also observed the conversion of tourmaline into chlorite in chloritic schist containing tourmaline, at Pfitsch in the Tyrol.

The conversion of tourmaline into chlorite consists chiefly in the introduction of magnesia and water, with displacement of alkalies.|| Alumina is separated in greater or less amount, accordingly as chlorite or lepidolite is formed. Boracic acid has not

* Loc. cit. p. 697.

† Blum.—Nachtrag, p. 28. Naumann.—Erläuterungen, &c., ii, 190, et. seq. and 201, et. seq. Several remarkable phenomena observed by Oehlschlägel are described here. German edition, ii, 443, et. seq.

‡ Reise, i, 256.

§ Loc. cit. ii, 502.

|| In some varieties traces of alkalies were found by v. Kobell.

been found in the chlorite hitherto analyzed, it would, therefore, be interesting to ascertain whether or not it is present in the chlorite derived from tourmaline, and a comparative analysis of the tourmaline at one end of a crystal, and of the chlorite at the other end, would probably furnish a further elucidation of the process of conversion.*

Steatite with the form of tourmaline.—This pseudomorph was observed by Blum † in red tourmaline from Rozena. The alteration generally commences at one end of the crystal, and extends over the surface more than into the mass. In the granite of Thiersheim there are indications of the conversion of black tourmaline into a leek-green substance resembling steatite.‡

Decomposition of tourmaline.—The loss of the usual lustre appears to be the commencement of the alteration. Sometimes it is only particular faces that become dull or even rough and full of holes, while others retain their full lustre. Sometimes the same face is dull or rough at one end, and presents the full lustre at the other end. In the holes there is a brown incrustation, that I have observed in a great number of specimens, and generally laminæ of mica. Rammelsberg found in the hollow of a tourmaline crystal a reddish argillaceous mass with a few laminæ of mica. At a very disintegrated part of a large tourmaline crystal I found a mixture of tourmaline and mica.

The analysis of silver-white mica originating from black tourmaline,§ shows a diminution of the peroxide of iron to the extent of 8 per cent. Generally this pseudomorphous mica is silver-white; but Blum describes some that had a dark greenish-grey and brown colour; Rammelsberg describes some that had a yellowish-white colour, and black mica in the cavities of black tourmaline.

The white mica contains but little iron, so that the conversion of black tourmaline into white mica presupposes the partial elimination of the peroxide of iron; and this is in accordance with the association of hydrated peroxide of iron with white mica at the decomposed parts of tourmaline crystals.

Assuming that the tourmaline II *b* || had originally the same

* In the Edinburgh Museum of Natural History there is a pseudomorph consisting of chlorite after tourmaline. The chlorite is partly an incrustation, and also constitutes part of the mass of the pseudomorph.

† Die Pseudomorphosen, p. 134.

‡ There is a pseudomorph of this kind in the Edinburgh Museum.

§ See Chapter xxxviii.

|| See ante, p. 258.

composition as the tourmaline II α , it would follow that a portion of the boracic acid had been separated, and peroxide of iron introduced, but that otherwise there had not been any essential alteration. The presence of laminae of mica at the interior of the tourmaline shows unmistakably that conversion into mica had commenced. If this mica had been analyzed and had been found to contain less iron than the tourmaline, it might have been inferred that there had been a partial elimination of peroxide of iron, in consequence of the conversion into mica. The iron ochre in the hollows would in that case result from this separation; a portion of it might, however, have penetrated into the tourmaline mass, and have given rise to the increased amount of iron. If the colour of the mica had been stated in the description it would have been possible to determine whether it was potash mica or magnesian mica, and then there would be some ground for an opinion as to the probability of the assumed change.

Reuss* describes tourmaline in which the faces of the three sided prism presented deep furrows. All the faces have a considerable lustre at the prominent parts. Next to the periphery is a layer 0.5 line thick, perfectly preserved and fresh but at the interior of the crystal are a number of fissures and cavities parallel to the faces of the prism, so that there remains only a porous skeleton of tourmaline, the gaps being filled with hydrated peroxide of iron. Therefore all the constituents of the tourmaline had been removed except the peroxide of iron.† No mention is made of mica.

Hermann‡ states that almost all specimens of tourmaline contain carbonic acid, but he denies the presence of fluorine. However Rammelsberg did not find a trace of carbonic acid in any one of the thirty specimens analyzed by him, though they all contained fluorine. As tourmaline never contains much lime, only a very small amount of carbonate of lime could have been formed. But if carbonated water extracted the protoxide of iron as carbonate, this substance would soon have been decomposed by oxidation, as is shown by the frequent incrustation of hydrated peroxide of iron upon decomposed tourmaline.

As in the conversion of tourmaline into mica the boracic acid is entirely eliminated,§ it is probable that part of the iron, which

* Lotos, Zeitschrift für Naturwissenschaften, Jahrg. iii, 239.

† An analysis of this oxide of iron would be very desirable for the purpose of ascertaining whether it contains any of the other constituents.

‡ Journ. für prakt. Chemie. xxxv, 232.

§ See Chapter xxxviii.

is always eliminated in this alteration, may be separated as borate of protoxide of iron, but in the absence of analyses of the hydrated peroxide of iron from decomposed tourmaline, this point cannot be determined.

In the alterations and decomposition to which tourmaline is liable there is the common feature that alumina is always separated, until in steatite, the final product of alteration, it disappears entirely. Besides this the decomposition may take two different directions; in the conversion into mica, alkalis are introduced, while in the conversion into chlorite and steatite the alkalis present in tourmaline are separated. A constant increase in the amount of magnesia takes place, at least in the conversion into chlorite or steatite; the formation of steatite must be regarded as merely a continuation of the conversion into chlorite. Moreover, it appears in these alterations there is always an introduction of water; it is present even in the mica and to a large amount in the chlorite and steatite. Lastly, since mica is capable of being converted into steatite it may be expected that any mineral which may be converted into mica will ultimately yield steatite. It is indeed the case that with the exception of corderite and felspar, all the other minerals which are capable of being converted into mica, are likewise capable of being converted into steatite.

CHAPTER XXXI.

ANDALUSITE, CHIASTOLITE, AND CYANITE.

THESE minerals are essentially anhydrous silicates of alumina. They are not sensibly acted upon by acids, either before or after ignition.

Occurrence.—Andalusite occurs most frequently in micaceous schist and in gneiss; less frequently in granite, serpentine, and quartz rock. Sometimes it occurs crystallized, sometimes in a compact form with a granular or columnar structure.

Chiastolite occurs most frequently in clay slate, less frequently in micaceous schist. It is most abundant in a rock intermediate between micaceous schist and clay slate occurring in Algeria.* It is always crystallized and the crystals present the remarkable feature of rhombic spaces in the middle filled with clay-slate

* *Exploration Scientifique de l'Algérie*, Paris, 1848, p. 58.

like that in which they are imbedded, the sides being parallel with the faces of the crystal. Black marks in chiastolite consisting sometimes of a carbonaceous substance and sometimes of clay-slate or of both, originate from the clay-slate.

Formation.—The occurrence of chiastolite in clay-slate, together with fossil remains of trilobites and the presence in it of volatile substance to the amount of 1 per cent., excludes all doubt as to its formation in the wet way, from the silicates of alumina in the clay-slate. This is likewise the case with regard to andalusite for it occurs in micaceous schist and clay-slate under similar conditions.*

Cyanite occurs in micaceous-, and talcose-schist, in granite, granulite, eklogite and upon quartz dykes in clay-slate. This latter occurrence together with its occurrence as a pseudomorph after andalusite proves that it is formed in the wet way.

Composition.—Andalusite and chiastolite are identical, or at most merely varieties.† The earlier analyses gave very discordant results, owing principally to the circumstance that andalusite is frequently converted into cyanite. The andalusite containing the largest amount of silica was the purest; that containing the smallest amount of silica was most impure and had been converted more or less into cyanite.

The analyses that are evidently incorrect are excluded.

	I.	II.	III.	IV.	V.	VI.
Silica	40·17	39·09	39·99	39·24	36·67	37·63
Alumina	58·62	58·56	58·60	59·49	60·00	59·14
Peroxide of iron .....	....	....	0·72	0·63	1·33	0·86
Oxide of manganese	0·51	0·53	0·83	....	....	....
Lime	0·28	0·21	....	0·51	0·93	2·01
Magnesia ....	....	....	....	0·25	....	0·50
Volatile substance ....	....	0·99	....	....	....	...
	99·58	99·38	100·14	100·12	98·93	100·14
O. Q.	1·321	1·355	1·346	1·383	1·505	1·456

- I. Andalusite from Lisenz in the Tyrol

II. Chiastolite from Lancaster

III. Andalusite from Lisenz
- Bunsen ‡

Bunsen ‡

A. Erdmann §

* Breithaupt. Paragenesis, p. 36.
† Bunsen. Poggend. Annal. xlvii, 186.
‡ Loc. cit.
§ Berzelius' Jahresbericht, xxiv, 311.

		Analyzed by
IV. Inner portion of andalusite crystals from the Langtauer Valley in the Tyrol	}	Hubert *
V. Outer portion of the same crystals		Hubert *
VI. Pseudomorphous cyanite after anda- lusite, from Krumbach in Styria	}	Hubert *

As cyanite is so difficult to decompose, it is probable that several analyses of it, particularly the older ones, are incorrect and indicate too large an amount of silica. This is especially the case with the analyses by Klaproth and Vanuxem.

	VII.	VIII.	IX.	X.	XI.	XII.
Silica	36.67	36.9	37.0	34.4	37.36	36.60
Alumina	63.11	64.7	62.5	61.86	62.09	62.66
Peroxide of iron	1.19	....	....	0.52	0.71	0.84
	100.97	101.6	99.5	96.78	100.16	100.10
O. Q.	1.566	1.496	1.518	1.626	1.505	1.552

VII. Cyanite from St. Gotthard	Analyzed by Rosales †
VIII. The same mineral	Arfwedson ‡

Another analysis gives only 34.33 per cent. silica, and 1.698 for the oxygen quotient, which is evidently too high.

IX. Cyanite from Røraas in Norway	Arfwedson §
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Another analysis gives 36.40 per cent. silica, and 1.575 as the oxygen quotient, which is also too high.

X. The same mineral containing 0.19 per cent. oxide of copper	} A. Erdmann
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The considerable deficiency of 3.03 per cent. renders it probable that this analysis is incorrect, and hence the high oxygen quotient.

XI. Cyanite from the Tyrol	A. Erdmann ||
XII. Cyanite from St. Gotthard	Marignac ¶

* Jahrbücher der geolog. Reichsanstalt zu Wien. Jahrgang i, 350 and 358.

† Poggend. Annal. lviii, 160.

‡ Schweigger's Journ. xxxiv, 206.

§ Ibid, p. 207.

|| Berzelius' Jahresbericht, xxiv, 311.

¶ Annal. de chim. et phys. xiv, 49.

	XIII.	XIV.	XV.	XVI.
Silica	37.30	37.65	37.51	36.6
Alumina	62.66	59.87	60.01	61.9
Peroxide of iron	1.08	1.87	1.49	trace
Lime ...	....	0.58	0.48	....
Magnesia ....	....	0.38	0.46	trace
	100.98	100.35	99.95	98.5
O. Q.	1.525	1.474	1.477	1.519

Analyzed by

- XIII. Cyanite from Greiner in the Zillerthal } Jacobson *
 XIV. Andalusite from Fahlun } L. Svanberg †
 XV. Crystallized andalusite from Munzig, } Kersten ‡
 in the Triebischthal
 XVI. Chiastolite from the micaceous schist } Renou §
 near Bona in Algeria

	XVII.	XVIII.	XIX.
Silica	37.65	36.16	36.31
Alumina	62.41	63.52	62.42
Magnesia ....	...	...	0.70
	100.06	99.68	99.43
O. Q.	1.490	1.578	1.560

Analyzed by

- XVII. Sillimanite from Chester, Connecticut } B. Silliman ||
 XVIII. Buchholzite or fibrolite from Brandy- } B. Silliman ||
 wine Springs, Connecticut
 XIX. Fibrolite from the Carnatic (Bournon) } B. Silliman ||

In I, II and III it appears that the oxygen quotient of unaltered andalusite is so near 1.333 that this may be taken as

* Poggend. Annal. lxxviii, 416.

† Berzelius' Jahresbericht, xxiii, 279.

‡ Journ. für prakt. Chemie. xxxvii, 162.

§ Exploration Scientifique de l'Algérie, Paris, 1848, p. 53.

|| American Journal, Ser. 3, viii, 10.

the normal value. The somewhat higher oxygen quotient of IV shows that the inner portion of the andalusite crystals, which have been entirely converted into cyanite at the outer part, has already experienced some alteration. The oxygen quotient of V agrees with that of cyanite. In the pseudomorph represented by VI the alteration does not appear to be complete, for the oxygen quotient is less than the normal value.

The specimens represented by XIV and XV show that minerals which have all the appearance of andalusite, may have almost exactly the composition of cyanite, for the oxygen quotient in both instances is very nearly that of cyanite. It is probable, therefore, that these minerals are pseudomorphs after andalusite. It is interesting to observe that chiastolite is capable of conversion into cyanite.

The oxygen quotients of the specimens of cyanite represented by VIII, IX, XI, XII and XIII are so near 1.5 that this may be taken as the normal value. Probably the high oxygen quotients of VII and VIII arise from defective separation of the silica from the alumina.

The oxygen quotient of XVII is so near that of cyanite, that sillimanite may be regarded as chemically identical with that mineral. G. Rose,* however, remarks that these minerals are distinct so far as regards crystal form, cleavage and specific gravity.

Whether the higher oxygen quotients of XVIII and XIX arise from the above-mentioned cause, or whether the buchholzite or fibrolite is chemically different, I am unable to decide, although the former case appears to me most probable.

Cyanite with the form of andalusite.†—All specimens of andalusite whose oxygen quotient is higher than 1.333 have already undergone alteration. The conversion of andalusite into cyanite consists in a partial elimination of silica which very frequently, and perhaps always, is associated with cyanite in the form of quartz.‡

As the andalusite of Lienz occurs in a granite rock in which it appears to occupy the place of felspar,§ and as it likewise occurs

* Mineral system, p. 80.

† Blum.—Die Pseudomorphosen, p. 17, and Nachtrag, 2, p. 10.

‡ Fuchs.—Schweigger's Journ. xxxiii, 379.—Arfwedson.—Ibid. p. 206. The pseudomorph represented by V likewise occurs imbedded in quartz.

§ V. Senger.—Versuch einer Oryktographie von Tyrol, 1821, p. 26.—It is worthy of notice, that in this rock there are pseudomorphous cyanite, mica, and steatite after andalusite, which is further evidence that the processes of alteration taking place in a rock may be very different though probably at different periods.

imbedded in felspar, there can be no doubt that in these instances it has originated from felspar. In the conversion of felspar into kaolin there is a diminution of the silica and an increase in the amount of alumina; and if this process of alteration were continued still further, the composition of andalusite would ultimately be attained. The conversion of andalusite into cyanite shows that this alteration goes on still further. It is deserving of notice that andalusite, chiastolite and cyanite occur only in crystalline and sedimentary rocks which consist chiefly of orthoclase or its derivatives. So that it would appear there is not any crystalline silicate of alumina formed in the decomposition of labrador.

Mica with the form of andalusite.—Andalusite is very frequently covered with mica.* Sometimes, also, it constitutes part or the whole of andalusite crystals, as Blum† observed in some specimens of the coarse-grained granite of Lisenz. When the andalusite crystal was broken in three parts, it was evident that the alteration commenced at one end of the crystal that was not perfectly developed, extending over the surface and into the mass of the crystal, while at the other end of the crystal the andalusite had entirely disappeared, and was replaced by a confused aggregate of greenish and yellowish-white mica. Andalusite from another locality presented the same characters. It will subsequently be shown that in this alteration potash mica is formed.‡

A true pseudomorphous mica after chiastolite is not known; therefore all that can be said as to the conversion of the one into the other, is, that chiastolite crystals, covered with laminæ of mica, sometimes occur in clay slate, and that according to Arfwedson,§ the composition of a chiastolite crystal, from Brittany, that was so soft as to receive impressions of the nail, was very nearly the same as that of the mica from Kimto in Finland. I have placed beside the analysis|| of this mineral, an analysis by Schafhäütl of a mineral from the Zillerthal, which he calls indurated talc, but which corresponds so closely with the specimen of chiastolite in composition that it may be regarded as an analogous product of alteration.

* English edition, i, 46.

† Loc. cit. p. 91, and Nachtrag, p. 24.

‡ See Chapter xxxviii.

§ Berzelius' Jahresbericht, xi, 205.

|| Annal. der Chemie. und Pharm. xlvi, 336.—The composition of this mineral corresponds entirely with that of mica; but its appearance is more analogous to that of talc, although the composition is very different. This is a striking instance of the identity of two minerals in composition, while the physical characters are wholly different.

	Chiastolite, Arfwedson.	Mica, H. Rose.	Indurated Talc.
Silica	46.3	46.36	47.05
Alumina ...	36.0	36.80	34.90
Peroxide of iron	2.6	4.53	1.50
Potash	11.3	9.22	7.96
Magnesia	2.7	....	1.95
Hydrofluoric acid ....	....	0.71	Soda 4.07
Water	1.1	1.84	1.45
	100.0	99.46	98.88

As this altered chiastolite is very similar to mica, it is very probable that it may be actually converted into mica.

Mica with the form of cyanite.—The latter mineral is frequently covered with laminae of mica which are generally situated upon the faces in a direction parallel to the most perfect planes of cleavage. They also penetrate into the crystals in the same directions, and sometimes in such quantity as to form a mixture of mica and cyanite, while at other places the cyanite has entirely disappeared.*

Steatite with the form of andalusite.—Near Göpfersgrün† steatite sometimes occurs with crystal form similar to that of andalusite. Blum‡ discovered among the andalusite of Lisenz, crystals two or three inches long that were entirely converted into steatite; others presented this alteration only at the surface.

The conversion of chiastolite into steatite is so frequent that it is very rarely chiastolite crystals are found which have not to some extent undergone such a change. The chiastolite crystals from Lancaster, Massachusetts; from Héas Valley in the Pyrenees; and from Gefrees in Bavaria present very distinct instances of displacement pseudomorphs. The alteration commences at the surface and extends inwards.§

Talc with the form of chiastolite.—Blum|| describes very distinct displacement pseudomorphs consisting of talc after chiastolite from

* Blum. Nachtrag 2, p. 25.

† Goldfuss and Bischof. Physikal. statist. Beschreibung des Fichtelgebirges, 1817, ii, 113.

‡ Die Pseudomorphosen, p. 129, and Nachtrag, p. 113.

§ As so many minerals are converted into steatite, talc, serpentine, chlorite, and mica, I shall, in order to avoid repetition, treat of the chemical features of these instances of pseudomorphism in a general manner, in the chapters devoted to these minerals.

|| Nachtrag, p. 64.

Lancaster. In one specimen, consisting of four crystals over two inches long, the whole mass consists of white or yellowish-white laminæ of talc. The analyses of altered chiastolite crystals, already quoted, admit of the conjecture that the talc is not always pure; but is a substance resembling mica in composition.

Conversion of cyanite into talc.—Blum* found cyanite crystals that were covered with a crust of talc, and at the interior appeared to consist of fine laminæ of talc. In one specimen the laminæ of the talc coincided with the direction of the cleavage planes of the original cyanite. A specimen of cyanite converted into talc, from Wustüben, was analyzed by me with especial reference to the amount of silica and of magnesia. This mineral did not evolve water at 212° F., but when ignited gave out an empyreumatic odour. The results of my analysis are :

	A.	B.
Alumina and Peroxide of iron....	0·48	} extracted by hydrochloric acid.
Magnesia	0·22	
Silica	41·35	
Magnesia	0·49	
Alumina and peroxide of iron } estimated from the deficiency }	56·50	Talc 2·16
Loss by ignition	0·96	Cyanite 97·82
	100·00	100·00

This specimen of cyanite would, therefore, be among those with a large amount of silica, analyzed by Gillet de Laumont. Calculating both quantities of magnesia as talc, the result B is obtained.

Consequently, the conversion of the cyanite into talc had not advanced far; and, probably, the talc merely formed a thin layer on the surface, giving the crystal the appearance of having been entirely converted into talc. This alteration is rare; for it is only in the analysis of cyanite by Saussure, that magnesia is indicated, to the amount of 2·3 per cent. But as this analysis was made at a time when the means for separating magnesia from other earths were very imperfect, no great reliance can be placed in it.

Minerals which, like andalusite, chiastolite, and cyanite, are not acted upon by acids to any appreciable extent, and whose

* Die Pseudomorphosen, p. 108, and Nachtrag, p. 65.

constituents do not enter into combination with the ingredients of the atmosphere, are not liable to disintegration by exposure; so that when they are found in a state of alteration, this can be attributed only to an interchange of constituents.

CHAPTER XXXII.

CORDERITE.

Occurrence and composition.—This mineral is not frequently met with. It occurs in granite, gneiss, in a basaltic rock, in diorite, in glassy felspar rock, and as rounded pebbles. The essential constituents of corderite are silicates of alumina and magnesia, at least that would appear to be the case from the analyses by Th. Scheerer, of the corderite from Krageroe in Norway.* This contains only 0·96 per cent. protoxide of iron, and 1·12 per cent. lime, while the former substance amounts in some specimens of corderite to 10·7 per cent. Corderite free from iron appears to be composed of:—

					Oxygen.
Silica ....	....	....	....	51·76	5
Alumina ....	....	....	....	34·35	3
Magnesia ...	....	....	...	13·69	1
					—
					100·00
O. Q. ...					0·8
				

In the corderite containing iron, alumina is replaced by some protoxide of iron.

Alteration of corderite.—This mineral has never been found with the form of any other mineral; but, according to Haidinger, it is the initial member of a series of minerals, which are products of its alteration, including fahlunite, chlorophyllite, bonsdorfite, esmarkite, perhaps oosite, weissite, praseolite, gigantolite and pinite, and terminating with mica, in a pseudomorphic condition.†

* Poggend. Annal. lxxviii, 319.

† Abhandlungen der königlich. böhmischen Gesellschaft der Wissenschaften. Folge 5, p. 4.—In the German edition—ii, 384 et seq.—I have replied to the objections made by Scheerer to the inferences that Haidinger has drawn from

Blum * adds to these the pyrargillite of Brunholt and Helsingfors, and aspasiolite.† The derivative minerals are much more frequent than corderite.

The conchoidal structure exists not only in compact masses, but also in crystals of corderite and more or less distinctly in all the products of its alteration with the exception of pinite and mica. This conchoidal structure appears to be the reason why this mineral is more liable to decomposition than many others, for it facilitates the penetration of water. The corderite substance between the layers is softer than at the interior, and laminæ of mica are frequently found there. In the conchoidal layers of chlorophyllite, unaltered corderite occurs at some parts, but not in those of gigantolite. In the latter, the inner portion of the layers is compact, and the outer portion is entirely converted into mica. Those specimens of corderite, in which the conchoidal structure is least developed, appear to have been converted into a compact mass consisting of fahlunite or pinite.

The hard fahlunite from Fahlun, appears in some instances, according to Blum, to be the first product of the alteration of corderite, and that from which others are produced. In this alteration the hardness and specific gravity are less affected than the lustre, transparency, and colour. The alteration, however, is not completed; for fahlunite may be converted into mica.‡

In the alteration of corderite it would appear that the whole of the products are not always formed in succession, but that some one or other fails, according to circumstances. There are not, perhaps, any pseudomorphs of this series, in which mica is not present to some extent; so that this final product would appear to be always formed, together with other members of the series. In a specimen belonging to the Berlin collection of minerals, I found, upon a fracture-surface of a corderite crystal, green laminæ of mica together with hard blue corderite in the same plane; the direct conversion of one mineral into the other was unmistakable, and all the intermediate products of alteration failed.

It has already been remarked that mica appears to follow observed facts; and have likewise pointed out the inconsistencies arising from the assumption that the products of the alteration of corderite, which are frequently associated in one specimen and present the most diverse transitions, are original formations.—German edition, ii, 382 et seq.—English edition, i, 48.

* Nachtrag zu den Pseudomorphosen, p. 32.

† In the collection of minerals belonging to the Berlin University I found specimens of aspasiolite that left no doubt as to their having been formed from corderite.

‡ For a description of the individual members of the series, see German edition, ii, 372, et seq.

immediately after fahlunite, the probable first product of alteration, or to have been formed at the same time, although the other products of alteration fail altogether. In a similar manner pyrargillite crystals sometimes consist entirely of an aggregate of mica laminae arranged in all directions, and sometimes whole layers of gigantolite and portions of those of chlorophyllite consist of mica laminae. Some specimens of pinite consist almost entirely of very minute laminae of mica.

Freiesleben* first described a mineral resembling pinite, from granite. Ficinus† described a mineral, under the name of columnar mica which was very probably altered pinite. Blum‡ had previously pointed out that mica occurs with the form of pinite, as is shown very distinctly in the granite of Heidelberg. The alteration generally commences at one end and progresses gradually. This alteration has subsequently been shown by Blum§ to be so frequent that there is not, perhaps, any specimen of pinite without at least a few laminae of mica at the surface or at the interior of the crystals.

Some of the columnar aggregates and laminar masses of mica occurring in granite and gneiss, may, perhaps, originate from pinite that has been entirely altered; for pinite occurs in both gneiss and micaceous schist. Probably the columnar form of pinite might in such instances be recognized.

The mineralogical characters of the various minerals included under the general name of pinite, furnish, as Blum remarks, so little evidence of the individuality of this mineral as a species, that there is still greater reason for regarding them as pseudomorphous substances. The compact and amorphous character of the mass, the absence of cleavage, the dull appearance of the crystals inside and out, are all characters that are foreign to individual mineral species. In addition to these may be mentioned the differences in the results of analyses of specimens of pinite, which may likewise be based upon the different pseudomorphous conditions of the minerals. Therefore, Haidinger's opinion that pinite may be altered corderite, cannot, as Blum says, be called in question. The

* Magazin für die Oryktognosie von Sachsen, 1830, iv, 187 and 188.

† Schriften der Gesellschaft für Mineralogie zu Dresden, 1819, ii, 198 et seq.

‡ Leonhard's Zeitschrift für Mineral. 1828, 683 et seq.—In the Berlin collection of minerals I found among the specimens of pinite one labelled "blackish-brown, nearly pinchbeck-brown mica—pinite—in six-sided prisms, which, together with crystallized felspar and quartz, is a constituent of a particular kind of granite at Schneeberg. This is probably the earliest notice of the relation between mica and pinite.

§ Nachtrag, p. 17.

association of pinite and corderite at Haddum, Connecticut, contributed to render the relation between these minerals more intelligible, and hence arose the opinion that pinite is a derivative of corderite.*

The conversion of corderite into mica is important in a geological point of view, for it is very probable that corderite, which is sometimes so abundant in gneiss, has undergone this alteration, particularly as corderite is less prominent where the gneiss is very micaceous, and sometimes fails entirely when the gneiss passes into micaceous schist.†

According to the investigations of Ad. and W. Knop,‡ pinite may originate from a mineral that does not belong to the corderite series. A mineral resembling pinite with the form of labrador is copiously disseminated throughout the greenstone schist of Harthau near Chemnitz, as yellowish- and greenish-white patches and presenting in some instances distinctly the fracture and form of labrador. At some places unaltered labrador crystals likewise occur. Those masses which present the form and fracture of labrador appear, by the aid of the microscope, to consist of very small closely packed scales of mica.

	I.	II.
Silica	55.18	54.67
Alumina ...	27.51	27.89
Protoxide of iron	4.08	Fe ² , O ³ 0.31
Protoxide of manganese	trace	...
Lime	0.30	10.60
Magnesia	1.22	0.18
Potash	3.37	0.49
Soda	4.50	5.05
Fluorine	0.08	...
Water	3.74	...
	99.98	99.19

I. Pinite with the form of labrador.

It contains the largest amount of soda yet found in any specimen of pinite, and this may be ascribed to its formation from labrador.

II. Labrador from the greenstone porphyry of Campsie in Scotland.§

* Silliman's American Journal, 1841, xli, 354. Haidinger's remarks on the different directions of the laminæ of mica, in a twelve-sided prism of pinite, from the above locality. German edition, ii, 378.

† Ibid, ii, 394, et seq.

‡ Chemisch-Pharmaceutisches Centralblatt, 1851, p. 754.

§ Le Hunte.—Edinburgh new Phil. Journ. July 1832, p. 86.

This serves for comparison with I; supposing the lime displaced by potash a composition would result very similar to I.

The patches above mentioned effervesce with acids, showing that there has been an actual separation of lime from the labrador that has been converted into pinite.

Mica never contains such a large amount of silica and soda as the pinite I, so that in the conversion of pinite into mica there must be elimination of silica and substitution of potash for soda. The presence of quartz together with calc-spar in these patches shows that there has been a separation of silica. In this way the alumina may be relatively increased so far as to attain the amount present in true potash mica. In the pinite analyzed by Rammelsberg* the silica did not amount to more than in potash mica. The composition of the pinite of Pardoux is indistinguishable from that of potash mica.

The following table contains the results of the analyses of corderite and of the products of its alteration, so far as relates to the amount of magnesia, potash, soda and water, which are the only constituents to be taken into account in studying the chemical features of this alteration.

	Magnesia.	Potash.	Soda.	Water.
Corderite ....	..	..	..	..
Nine analyses	10 to 11.45	0	0	0.60 to 3.10
Two ,, ...	8.2 to 9.50	0	0	1.50 to 2.10
Two ,, † ...	12.75	0 ‡	0	1.02
Praseolite	13.73	0	0	7.38
Chlorophyllite....	10.91	0	0	6.70
Esmarkite	10.32	0	0	5.49
Weissite	8.99	4.10	0.68	3.20
Aspasiolite	8.01	0	0	6.73
Fahlunite §	6.04	0.94 — 1.98	0 — 4.45	8.65 — 11.66
Pyrargillite	2.90	1.05	1.85	15.47
Gigantolite	2.63 — 3.80	2.70 — 5.44	0.86 — 1.20	5.89 — 6.00
Pinite	2.86	7.89	0.95	5.39
„	2.48	10.74	1.07	3.83
„	2.26	9.00	0.46	5.45
„	1.30	9.14	..	4.27
„	1.02	6.52	0.40	7.80
„ ....	....	9.05	1.78	5.03
Columnar mica	0.80	11.20	0	1.2

* Supplement 3, p. 94, and Suppl. 4, p. 78.

† Excluding those which are evidently incorrect.

‡ L. Gmelin found 1 per cent. of potash only in one specimen of corderite, but leaves it undecided whether it was accidental or not.

§ In the analyses of fahlunite, gigantolite, weissite, and pinite, more or less organic substance was found.

It follows from the above data that—

1. The pseudomorphic alteration to which corderite is liable, commences with introduction of water, the amount of which decreases, however, when the final product of alteration, the mica is formed. Corderite itself contains some water; but in the earlier products of its decomposition the amount of water is considerably larger.

2. The amount of magnesia in corderite is tolerably constant, but the amount of water varies more, although it is not inversely proportionate to the magnesia. However, there cannot be any doubt that the larger amount of water indicates that considerable alteration has taken place.

3. In the products of this alteration from praseolite to pinite, the amount of water does not increase in the same proportion as that of magnesia decreases. It would appear, therefore, that corderite may be converted sometimes into one, sometimes into another of the products of alteration.

4. The products of the alteration of corderite form two series; one including praseolite, chlorophyllite, esmarkite, and aspasiolite; the other fahlunite, weissite, pyrargillite, gigantolite, and pinite. In the formation of the substances belonging to the first series, alkalies are not introduced; but in the formation of those belonging to the second series, alkalies are introduced; and in pinite there is the maximum amount of potash, equal to that in columnar mica.

5. Among the products of the alteration of corderite, pinite contains the smallest amount of magnesia; there is not, however, any constant relation between it and the amount of water or of alkalies. It is probable that a more extended analytical examination of the other products of the alteration of corderite would show as great a variation in the relative amounts of the constituents as there is in pinite; for these substances have not any specific individuality, but merely represent more or less advanced stages of the alteration.

6. The alteration to which corderite is subject has one essential feature, which is the elimination of magnesia and the introduction of water and alkalies.

The composition of corderite is very like that of magnesian mica; so that it might be supposed there would be a tendency to conversion into it by introduction of alkalies. Haidinger states that the mica in chlorophyllite is sometimes white, sometimes green, and is uniaxial; consequently, analogous to magnesian mica.

In other of the products of alteration, both uniaxial and biaxial or potash mica occur. The latter would appear always to occur in pinite, unless the reddish-brown mica in some specimens of pinite constitute an exceptional case. The only known analysis of mica that has originated from pinite shows that the mica is potash mica.

It is much to be regretted that Rammelsberg did not examine the mica separated from the specimens of pinite that he analyzed, for this would have furnished a means of ascertaining the relation they bear to each other in composition. However, there can be no doubt that it was potash mica, for there is no probability that magnesia would have been again introduced into pinite.

A specimen of mica, originating from fahlunite, that I received from Blum, had the following composition :

	I.	II.	III.
Silica	...	..	47·38 *
Alumina	14·15	14·16	28·31
Protoxide of iron	11·62	3·29	14·91
Magnesia	0·80	0·81	1·61
Potash	3·02	2·27	5·29
Soda...	...	0·25	0·25
Organic substance †	1·01	...	1·01
Loss by ignition	1·24	...	1·24
	31·84	20·78	100·00

I. Portion extracted by digestion for thirty-six hours with sulphuric acid.

The residue consisted of laminæ with silvery lustre.

II. Portion extracted by hydrofluoric acid.

III. Analysis of the mineral as a whole.

The circumstance that this mica appeared gritty when rubbed in an agate mortar, admits of the inference that it contained foreign substances, and upon further examination Blum found that it was mixed with very finely divided particles of fahlunite. Consequently, the conversion of this mineral into mica had not been completed, and the analysis does not give the actual composition of the mica. Assuming that the magnesia found represents fahlunite, the proportion of this mineral would be about 25 per

* Estimated from the deficiency.

† Apparent from the black colour of the sulphate of potash, and of the residue obtained after the action of hydrofluoric acid.

cent. of the whole. In other respects the per centage composition is like that of gigantolite. It is at least certain that the mica was potash mica.

By acting upon several specimens of micaceous schist in the same manner I obtained analogous silver-white laminæ of mica. In one instance the mica contained alumina, protoxide of iron and alkalies, in the same proportions as potash mica, and the mica laminæ represented by II likewise present this character. But if sulphuric acid extracts from magnesian mica, the whole or greater portion of the magnesia, together with some protoxide of iron, it would be converted into potash mica.

In the ordinary course of mineral alteration it is only carbonic acid that would act upon minerals in this way; and neither the magnesia nor the protoxide of iron would be so largely extracted from magnesian mica by it, as by sulphuric acid. The alteration would cease when the greater portion of the magnesia and the protoxide of iron had been extracted. As the amount of alumina in potash mica is always greater than in magnesian mica, there is not any separation of this substance, which is consistent with the fact that this earth is not extracted by carbonic acid. The elimination of bases from magnesian mica would involve a relative increase in the amount of silica; and this agrees with the constant greater proportion of silica in potash mica than in magnesian mica.

It would, therefore, appear from the above data that the magnesian mica which occurs among the products of the alteration of corderite, is probably converted into potash mica by the gradual elimination of magnesia and protoxide of iron; more particularly as potash-mica alone is found where the alteration is at an end, as in pinite. When it is remembered that the alteration to which corderite is subject, consists essentially in the elimination of magnesia, it is very possible that the same process may be continued after the formation of magnesian mica.

The very remarkable alteration of corderite would appear to be effected by carbonic acid and alkaline silicates, the magnesia being removed by the former as carbonate, while the latter enter into combination with the residual part of the corderite; and the diversity of the products of this alteration would appear to be dependent upon the circumstances prevailing in particular instances. As the silicate of magnesia is decomposed by carbonic acid only when in solution,* this substance must be extracted by water

* English edition, i, 2.

before it is decomposed. The presence of alkaline silicates in water has already been pointed out,* and as the alteration of corderite takes place in granite and gneiss, the felspar of which is liable to gradual conversion into kaolin, with simultaneous separation of alkaline silicates, the water that percolates these rocks would be capable of effecting this alteration. Moreover Blum has observed that granite in which pinite occurs is almost always disintegrated to some extent.†

It would be worth while examining specimens of altered corderite for the purpose of ascertaining whether the magnesia occurs as magnesite or bitter-spar, in the adjoining mass, for since corderite sometimes contains as much as 3 per cent. lime, the latter may be a product of its alteration, and indeed the fahlunite of Finbo is sometimes associated with bitter-spar.

Water percolating granite or gneiss would soon be deprived of its free carbonic acid, by the gradual decomposition of felspar, and would become impregnated with alkaline carbonates and silicates. The latter may indeed be introduced into the corderite that is undergoing alteration, but the carbonic acid requisite for decomposing the silicate of magnesia would be deficient. When on the contrary meteoric water with the full amount of carbonic acid, comes in contact with corderite, the separation of magnesia may be effected, but not the introduction of alkaline silicates, and in this way the formation of those products of the alteration of corderite, that do not contain alkalies, may be accounted for.‡

The elimination of magnesia and the introduction of alkaline silicates, would take place simultaneously, only when the water had become impregnated with alkaline silicates, by the decomposition of felspar, and still retained a portion of the free carbonic acid, and this might have been the case, because alkaline silicates and carbonic acid may exist together in solution.§

It is questionable whether elimination of magnesia, and introduction of alkalies and water is the only kind of alteration to which corderite is subject. Rammelsberg|| endeavours to show by means of his analyses of pinite that the proportion of the oxygen of the silica to that of alumina is the same as in corderite = 5 : 3. But as he has calculated the relative amounts of protoxide and peroxide of iron in accordance with this supposition his

* See ante, p. 115.

† Loc. cit. p. 49.

‡ See ante, p. 279.

§ See ante, p. 58.

|| Supplement 4, p. 179.

argument is inconclusive. It is scarcely to be supposed that in such considerable alteration as corderite is subject to, there should not be some influence exercised upon the silica and alumina, but probably analyses, however numerous, would not throw any light upon this.

Corderite is one of the few minerals which, containing silicate of magnesia, are liable to decomposition. It presents this character in common with olivine, and will be further treated of in chapter xxxvii.

CHAPTER XXXIII.

GARNET.

THIS mineral is imperfectly decomposed by hydrochloric acid; some kinds, however, are completely decomposed when boiled with the acid; silica separating in a pulverulent state. After intense ignition the calcareous garnet is readily decomposed by acids; the silica then separating in a gelatinous state. Other kinds of garnet require to be heated nearly, or quite, to melting before they can be acted upon in this manner by the acid. By this heating, the weight of the mineral is reduced one-fifth.* It has already been pointed out, that this character is evidence against the formation of the mineral by fusion.†

The red, green, brown, and black kinds of garnet present the greatest geological interest; the white and yellow varieties are more particularly interesting to the mineralogist.

Occurrence.—Red garnet is an essential ingredient of eklogite; it sometimes occurs abundantly in crystalline schistose rocks, in gneiss, micaceous-, hornblende-, talcose- and chloritic schists; also in granulite, granite, syenite, diorite, hornblende rock, serpentine, felspar-porphry, trachyte, and in the masses thrown out during the older eruptions of Vesuvius. It likewise occurs in clay-slate, granular limestone, particularly in the fissures, upon metalliferous lodes, and in alluvial deposits.

Green garnet occurs in micaceous schist, in granular limestone, and very frequently upon metalliferous deposits, particularly those of magnetic iron ore.

* Magnus—Poggend. Annal. xxii, 391.

† See ante, p. 83.

Brown garnet frequently occurs together with the red and green kinds.

Black garnet occurs in micaceous schist, in clay-slate, granular limestone, dolerite, diorite, cyanite, in volcanic rocks and upon metalliferous deposits.

So far as regards the composition of rocks, garnet is not very important, for notwithstanding its frequent occurrence, the rocks in which it appears as a constant constituent such as eklogite and garnet rock, do not occur either frequently or as very extensive masses. But from a geological point of view it is of far greater importance than tourmaline.

Composition.—According to the proportions which analyses show to exist between the oxygen of the monoxides, sesquioxides and silica, and which are the same in all kinds of garnet = 1 : 1 : 2, the oxygen quotient would be 1,* and their composition would be as follows :—

	I.	II.	III.	IV.	V.
Silica	40·31	42·45	37·08	36·5	36·08
Alumina	22·41	22·47	20·62	20·3	..
Protoxide of iron ....	..	9·29	42·30	..	..
Peroxide of iron ....	..	..	..	..	30·56
Protoxide of manganese ....	..	6·27	..	43·2	..
Lime ...	37·28	6·53	..	..	33·36
Magnesia ....	..	13·43	..	..	..
	100·00	100·44	100·00	100·00	100·00

I. Alumina-lime garnet ; grossular, hessonite, romanzovite.

II. Alumina-magnesia garnet ; black garnet from Arendal.†

III. Alumina-protoxide of iron garnet ; almandine.

IV. Alumina-protoxide of manganese garnet.

V. Peroxide of iron-lime garnet ; green, brown, and yellow garnet, melanite, rotholsite.

It is only the black garnet of Arendal that contains magnesia to such a considerable amount that the mineral must be regarded as a distinct variety ; in the other kinds of garnet the amount of magnesia is inconsiderable, and it appears as a substitute of lime. However in pyrope—oxide of chromium garnet—it amounts to 15 per cent. according to Moberg ; the protoxide of chromium to

* The general formula for garnet was given at p. 89.

† Analyzed by Trolle-Wachtmeister. Poggend. Annal. ii, 21.

4.18 per cent., and the protoxide of iron to 9.94 per cent.* In uwarowite—sesquioxide of chromium garnet—the oxide of chromium amounts to 22.54 per cent., and replaces part of the alumina which amounts to only 5.88 per cent. Both kinds of chrome garnet have the same oxygen quotient as the other kinds of garnet.

The iron in garnet is both in the state of protoxide and of peroxide, but their relative proportion has not been estimated.†

Formation.—The situations in which garnet occurs present many remarkable features which throw a light upon its origin, alteration, and decomposition. The more important of these are the following.

The garnet in micaceous-, chloritic-, hornblende-, and talcose schists is frequently associated with magnetic iron ore, and, in the former rock, with staurolite, at Taganai and Polewskoi. This is a very remarkable circumstance that will be treated of hereafter.

Mineralogists long since observed that garnet acts upon the magnetic needle.‡ v. Kobell found very distinct octohedrons of magnetic iron-ore in the midst of a perfectly unaltered garnet crystal.§ Ebelmen found in a black garnet a small quantity of uncombined peroxide of iron, which was reduced by gentle ignition in contact with hydrogen.|| At a white heat the whole was reduced, silicate of lime and metallic iron remaining. Garnet that is not magnetic sometimes acquires this character after fusion.¶ The magnetic character of garnet that has not been ignited would appear, therefore, to be owing to the presence of magnetic iron ore.

The occurrence of garnet in sedimentary rocks, together with, and imbedded in, minerals that can have been formed only in the wet way, furnishes ample evidence of its formation in the wet way. Thus olive-brown garnet occurs as crystals more than half an inch long in the clay-slate of Plas Newydd in Anglesea;** green garnet occurs in ordinary limestone, together with crystals of calc-spar, galena, and zinc blende at Sala in Sweden.†† At Hesselkulla small crystals of greenish garnet project from the

* Journ. für prakt. Chemie. xlii, 122.

† Hisinger—Schweigger's Journ. xxi, 260, and xxxvii, 434. Karsten. Ibid, lxv, 340. Trolle-Wachmeister. Poggend. Annal. ii, 26.

‡ Brugmann—Lithologia Groningana, etc., 1781, p. 50, and De Saussure—Voyage dans les Alps, v. 60.

§ Schweigger's Journ. lxiv, 285.

|| Berzelius' Jahresbericht, xxvi, 367.

¶ The reduction of the peroxide of iron in garnet is by no means general.—See German edition ii, 455 and 456.

** L. V. Buch—Geognostische Briefe, 1824, p. 127.

†† Bredberg—Schweigger's Journ. xxxviii, 11.

limestone which is scattered through the compact matrix. Small brown crystals of garnet likewise project from the compact matrix and from the calc-spar imbedded in it.* In a fine-grained sandstone at Bastogne, garnet occurs together with fossil remains.† Pyrope occurs together with calc-spar, quartz, cyanite, chalcedony, arragonite, and iron pyrites, in an argillaceous conglomerate; sometimes the granules of garnet contain crystals of gypsum.‡

Garnet occurs likewise associated with copper pyrites, malachite, variegated pyrites, magnetic pyrites, arsenical pyrites, tin ore, serpentine, chlorite, mica, epidote, chabasite, etc. Its frequent occurrence, together with calc-spar, both imbedded in, and covering it, is especially remarkable. Since in the latter case the crystal faces of the calc-spar are covered with a crust of garnet, it would appear that the garnet was replaced by calc-spar.§ In a specimen of garnet belonging to the Berlin collection I distinctly recognized the calc-spar to be of later formation than the garnet. Garnet also occurs associated with wollastonite.

Besides the substances already named, garnet sometimes contains crystals of iron pyrites.|| Trolle-Wachtmeister¶ found small brilliant particles of mica in the powder of the garnet from New York, which occurs in a very micaceous schist. v. Kobell** found in many of the small garnet crystals—almandine—from Hungary, a nucleus consisting of a quartz mass mixed with black laminæ of mica. Distinct crystals of actinote were likewise imbedded in the midst of an unaltered garnet crystal. Hess†† made an analysis of a garnet from Pitkaranda, in which the surfaces of union were covered with a crust of fluor spar, and the mass was intersected by copper pyrites and wernerite.

Moreover, the occurrence of garnet near Schwarzenberg ‡‡ and at the Teufelstein in Saxony,§§ where it is associated, in garnet rock, with several substances which, like iron pyrites, arsenical pyrites, etc., are decomposed by heat; does not admit of any

* Trolle-Wachtmeister.—Loc. cit.

† F. Sandberger.—Jahrbuch des Vereins für Naturkunde im Herzog. Nassau, ix, 88.

‡ In the Edinburgh Museum there is a fine specimen of this kind, in which a white substance that does not effervesce with acids, probably quartz, intersects the garnet.

§ Weibye—Jahrbuch für Mineral, 1849, p. 780.

|| G. Rose—Reise nach dem Ural, ii, 117.

¶ Loc. cit.

** Loc. cit.

†† Kastner's Archiv. v, 328.

‡‡ Freiesleben.—Geognost. Arbeiten, v, 1 et seq.

§§ Naumann.—Erläuterungen, &c., ii, 238.—German edition, ii, 459 et seq.

other origin being ascribed to garnet than that by the wet way. At the copper mine of Bogoslawsk, the garnet rock appears as layers which have been traced for 130 fathoms, and which have in some places a thickness of 20 fathoms.* Here, as in the mine at Schwarzenberg, garnet is associated with hornblende, actinote, magnetic iron ore and granular limestone. Near Arendal almandine occurs upon hornblende and augite crystals, or is associated with prehnite and magnetic iron ore crystals, or is intimately blended with epidote,† hornblende, and magnetic iron ore. In the latter case it appears as thick masses between the layers of magnetic iron ore and the gneiss.‡ In some of the fine grained dolerite, at the Kaiserstuhl, in which the amount of augite is small, small black garnet crystals sometimes occur abundantly.§ This association is not without significance, because there is a possibility that augite may be decomposed into garnet, hornblende, and magnetic iron ore, while calc-spar would be produced at the same time.||

I have in vain sought for some instance of the occurrence of garnet which might furnish evidence of its formation by fusion. It has already been shown¶ that the garnets in the masses ejected from Monte Somma cannot be regarded as products of volcanic action.

Various opinions are held with reference to the blocks found in the Fossa Grande; v. Buch regards them as erupted masses; L. A. Necker supposes that they have been transported to their present situation by water.** However, these opinions have no connection with the question, as to whether the fine crystallized minerals that they contain, are of volcanic origin or not.

If it is assumed that these minerals were formed in the crater by volcanic action, a difficulty arises from the fact that the garnet etc., occur together with calc-spar and chlorite, minerals which cannot possibly have been formed in this way. Although it may be supposed that under the influence of pressure the carbonic acid of the calc-spar and the water of the chlorite were prevented from escaping, still this could have been the case only so long as the masses were exposed to this pressure in the crater, and not after

* G. Rose.—Reise nach dem Ural, i, 400.

† See ante, p. 245.

‡ Weibye.—Archiv. für Mineral, &c., xxii 479 and 480.

§ Leonhardt. — Die Basaltgebilde, i, 197.

|| See Chapter xxxv.

¶ See ante, p. 94.

** German edition, ii, 464 et seq.

they had been thrown out, even if their temperature was not above that of boiling water, and they were moreover thrown out red hot. Therefore, calc-spar and chlorite cannot have been formed by fusion.

It will subsequently be shown, that calc-spar, quartz, and chlorite may originate from the decomposition of garnet, and it is possible that in the erratic blocks, these minerals may have been formed in this manner. The facts that the lime garnet from Vesuvius, and analyzed by Trolle-Wachtmeister,* was associated with sodalite in granules and as veins, although in a perfectly fresh condition, and that the bases were in such proportion to the silica as corresponded with the capacity of saturation, are, however, both in opposition to the opinion that calc-spar and quartz may be products of the decomposition of garnet.

These facts render it necessary for the supporters of the volcanic theory, at least, to suppose that the formation of the calc-spar, quartz and chlorite took place after the masses had been thrown out of the crater, while they ascribe a volcanic origin to the garnet, vesuvian, etc.

If Necker's opinion, that the blocks were at one time imbedded in lava, is correct, then garnet, vesuvian, etc., might be considered as having been formed during the slow solidification of the lava, but even then the calc-spar, quartz and chlorite must have been formed subsequently, because the cooling lava was exposed only to the ordinary atmospheric pressure. Perhaps, it may be supposed that the garnet and vesuvian in erratic blocks were formed during their slow cooling, and this might be the case with large blocks, but certainly not with volcanic bombs which cool within a few hours. In this case the crystals would according to Kobell's experiments, have been octohedrons and not dodecahedrons truncated at all the corners.

Lastly, if these bombs are regarded as disrupted fragments of old lava solidified within the crater, and in which garnet and vesuvian had been formed, this opinion would be in the main similar to that which represents these minerals as having been formed in the erupted lava during its solidification. Then if calc-spar and chlorite had been formed in the cavities of such masses of lava after they had cooled, these minerals would have been decomposed when the lava was again heated at the time of the eruption. But since these minerals are associated with garnet and vesuvian, this opinion cannot be maintained, and it can only be supposed that

* Loc. cit.

the formation of the calc-spar and chlorite took place subsequently to that of the garnet and vesuvian, and not by fusion, however the prior formation of these minerals may be supposed to have taken place.

The origin of the erratic blocks, in the Fossa Grande, certainly belongs to a prehistoric period, whether they are ejected masses, or transported masses of lava. Therefore the formation of the minerals they contain cannot be any more unaccountable than the formation of garnet in clay-slate. The occurrence of garnet under circumstances such as those just described is altogether irreconcilable with the opinion that it has been formed by fusion.

The above remarks will probably be sufficient to show that the occurrence of garnet, vesuvian, etc., in the erratic blocks at Somma does not furnish any greater evidence of their volcanic origin than their occurrence in similar blocks at the Lake of Laach.* Such an origin could be inferred only if these minerals were found in lava immediately after it had cooled. In a work,† published ninety-five years since, there is a statement that vesuvian had been found in recently erupted lava, but no great importance can be attached to it.

In conformity with all the facts that are known it must be inferred that the formation of garnet by fusion does not appear at all possible.

By melting garnet in a platinum crucible, v. Kobell ‡ found small octohedral crystals upon the surface of the blackish-green glass, and in a few drusy cavities. Garnet has never been found native with the octohedral form, and according to v. Kobell, the crystallization of the melted garnet would appear to be indicative of an altered arrangement of the constituents, and also that the decomposition by acids, of garnet that has been ignited, is connected with this change. He points out the striking similarity between these crystals, and those obtained by Klaproth § from vesuvian melted in a porcelain furnace. The melted glass presented, upon a drusy crust, protuberances terminated with four triangular and minutely striated faces.

* According to Nöggerath, garnets occur here in small splintered crystals, of a fine hyacinth colour, mixed with corderite, and imbedded in glassy felspar. Mica also occurs in the frequently very intimate mixture of corderite with glassy felspar; this is significant so far as regards the conversion of corderite into mica. — *Das Gebirge in Rheinland-Westphalen*, iii, 286.

† De Bottis *Istoria*, 1760, p. 34.

‡ Kastner's *Archiv*. V. 165 and X. 15.

§ *Beiträge*, etc., i. 34.

As these observations show that crystals may be formed from melted garnet and vesuvian, even when the solidification is rapid, the possibility of their formation by fusion would be decisively proved, if the crystals thus obtained were of the same form as that in which both minerals occur; but as this is not the case, the possibility of such an origin cannot be entertained, unless indeed it is assumed that the slow cooling of a melted mass induces the formation of crystals different from those formed when the same mass is rapidly cooled.*

Chlorite with the form of garnet.—The large garnets covered with chlorite and occurring in the mines at Fahlun, have long been known. Breithaupt† describes the conversion of aplome into a dark-green chloritic mass, so soft in parts that it would receive impressions of the nail.‡

Wiser§ observed in a druse of hyacinth garnet, some blackish-green, dull, opaque and soft crystals of the same size and form as the garnet crystals, which were yellowish-brown, lustrous, transparent, and hard. The former crystals consisted of a chloritic substance which gave off water when heated. One of these crystals was partially unaltered, while the greater portion was converted into the soft, chloritic substance. Subsequently Wiser|| described a very fine and characteristic specimen of this pseudomorph from the same locality.

Blum¶ describes a similar pseudomorph, which probably occurs between micaceous schist and serpentine. It consists of a number of dodecahedral crystals imbedded in a chloritic matrix from which they project, and are sometimes covered with calc-spar or bitter spar. They are smooth, blackish-green, with a fatty lustre, and appear to be aplome-garnet. However, the lustre and colour of these crystals has altered, and the hardness has been so much reduced that they may be cut with a knife. Some of them when broken show a nucleus of unaltered garnet, while the other part consists of a soft mass of very minute scales of chlorite; others were entirely converted into this substance. Therefore this

* Studer.—Lehrb. d. physikal. Geogr. und Geologie. p. 121.—states that garnet and vesuvian may be formed by fusion, and are found in the slags of blast furnaces, but it is not stated by whom such observations have been made.

† Poggend. Annal. lx, 595.

‡ There is a pseudomorph of this kind from Fahlun, in the Edinburgh Museum.

§ Jahrbuch für Mineral. 1842, p. 524.

|| Ibid. 1843, p. 298.

¶ Nachtrag, 2, p. 88.

alteration commenced at the surface, but did not extend inwards uniformly. The chloritic substance evolves water when heated, and presents all the characters of chlorite. This specimen is moreover remarkable from the presence of helvine* which projects from the chlorite.

In the Berlin collection of minerals, I saw a large garnet from Fahlun, with a very thin coating of chlorite. Several specimens of garnet from the chloritic schist of the Tyrol were quite covered with chlorite. A polished garnet presented a sudden transition into chlorite, and another was covered with a coating of iron pyrites.

Delesse † found a garnet imbedded in serpentine, which at the interior consisted of chlorite, while the outer portion was still red and unaltered. Near Toedestrand, in Norway, almandine occurs, in which the faces of union are numerous, and between them is a thin layer of chlorite or mica laminæ. The mineral is much disintegrated in the direction of these faces of union.‡

There have not been any analyses either of garnet which has been converted into chlorite, or of the products of the alteration; so that there would be some difficulty in pointing out the characteristic features of the alteration. If the garnet was highly calcareous, the alteration might have been effected by the reaction of bicarbonate of magnesia with silicate of lime.§ In the pseudomorphs described by Blum, carbonate of lime is actually present, and is probably a product of the decomposition of the silicate of lime.

Serpentine with the form of garnet.—The occurrence of this pseudomorph near Breitenbrunn and Schwarzenberg, in Saxony, has long since been made known by Freiesleben.|| But it was only by means of Karsten's analysis¶ that the product of alteration was shown to be serpentine. The greenish-black, and, at some parts, brownish-green serpentine, was mixed with a black mineral consisting of magnetic iron ore, especially where it was surrounded by calc-spar; it amounted to 17·5 per cent., and the serpentine to 82·5 per cent.

For the sake of comparison the following table contains, I, the

* German edition, ii, 487.

† Annal. des Mines. vii, 11.

‡ Weibye.—Archiv. für Mineralog. etc. xxii, 502.

§ English edition, i, 13, No. 16.

|| Geognostische Arbeiten, v, 29 and 179.

¶ Jahrbuch für den sächsischen Berg. und Hüttenmann, 1846, p. 39.

composition of the garnet of Teufelstein according to Karsten ; * II, that of the pseudomorphous serpentine ; III, the magnetic iron ore mixed with it :—

	I.	II.	III.
Silica	36·85	34·24	
Alumina	4·05	...	
Peroxide of iron	25·35	Fe O 3·38	17·50
Protoxide of manganese	0·95	Mn ² O ³ 0·41	
Lime	32·32	trace	
Magnesia ... ..	...	33·28	
Soda... ..	...	0·35	
Water and bitumen ... ..	...	10·62	
	99·52	= 82·28	+ 17·50

The greenish-brown colour of I showed that protoxide of iron was present as well as peroxide. By adding to the 3·38 per cent. protoxide of iron in serpentine, the 4·41 protoxide of iron in the magnetic iron ore, there would be 7·79 protoxide of iron, which may be supposed to have existed in the garnet that had been converted into serpentine. This quantity of protoxide of iron would require 0·89 oxygen for conversion into peroxide of iron ; and deducting this quantity from the 25·35 peroxide of iron in garnet, there would remain 24·46 magnetic oxide of iron. The brownish-green colour of the serpentine indicated the presence of hydrated peroxide of iron, so that it is probable a portion of the protoxide of iron in Kersten's analysis should have been calculated as peroxide, which would somewhat reduce the difference of 0·89 per cent.

According to these considerations the alteration may be supposed to take place in the following manner. The greater part of the magnetic oxide of iron in the garnet was separated as magnetic iron ore, and remained mixed with the serpentine. The presence of bitumen would account for the reduction of the remainder of the magnetic oxide of iron, and for its removal as carbonate of iron. By the reaction of the silicate of lime with bicarbonate of mag-

* Schweigger's Journ. lxxv, 345.—There is not any analysis of the garnet from the place where these pseudomorphs are found, and therefore the analysis of the garnet from Teufelstein, which is in the neighbourhood, is taken for comparison. This is the more admissible, since the garnet near Schwarzenberg resembles that of Teufelstein, in being of the green kind, which has a very uniform composition.

nesia, the former would be converted into silicate of magnesia ;* and by the action of sulphate of magnesia, or chloride of magnesium, the silicate of alumina would be decomposed, and a further quantity of silicate of magnesia formed.† Consequently, this process of alteration presupposes only the presence of bicarbonate of magnesia, sulphate of magnesia or chloride of magnesium, and some free carbonic acid, all of them substances which are very frequent in water. Naumann and Müller state that the garnet at Zöblitz and Greifenberg, in Saxony, are likewise converted into serpentine ; and according to G. Rose this may be observed in the specimens belonging to the Berlin collection.‡

G. Rose§ describes low serpentine hills in the neighbourhood of Miask, each of them containing a nucleus of rock similar to compact garnet. According to an analysis, by Sthamer, the oxygen quotient of this garnet is 0·762, so that the silica must preponderate greatly over the bases, a portion of which have, undoubtedly, been removed by water in consequence of far-advanced decomposition. Both rocks are much fissured, and the detached fragments of garnet are red at the surface ; those of serpentine snow-white, owing to decomposition.

Conversion of garnet into chlorite and serpentine.—H. Müller|| states that the garnet crystals, so abundantly imbedded in the serpentine at Greifenberg, are very often surrounded by a crust of minute laminæ of chlorite, which are perpendicular to the faces of the garnet crystals. Frequently the garnet is entirely converted into chlorite laminæ radiating from a centre. This phenomenon is particularly frequent at the surfaces of fissures. At the interior of the serpentine, the garnet is frequently surrounded with a crust of greyish-green substance, very similar to Breithaupt's pyknotrope, and sometimes passing into noble serpentine or asbestos. There is always a sharp line of distinction between this substance and the garnet, but at the outer side it often presents a gradual transition into the common serpentine, so that the two minerals cannot be distinguished. Frequently this crust can scarcely be detected ; and, generally, only a small but distinct nucleus of garnet is seen to be imbedded in it. Very often the garnet has disappeared entirely ; and only the product of its alteration remains. When the alteration is still further

* English edition, i, 13, No. 16.

† See ante, p. 69, No. 44.

‡ Poggendorff's *Annal.* lxxxii, 524.

§ Reise, ii, 98.

|| *Jahrbuch für Mineral.* 1846, p. 262.

advanced, even this is no longer recognizable; and the serpentine appears homogeneous. The previous existence of the garnet is, however, recognizable when the serpentine is disintegrated by exposure; it then becomes covered with an earthy, soft, brownish-yellow or yellowish-white crust, out of which the black serpentine, into which the garnet is generally converted, projects. A similar phenomenon is presented in the disintegration of chlorite that has been formed from garnet; it generally projects from the surface of the serpentine. Chlorite and talc occur abundantly as small laminæ in the serpentine; and at some places the serpentine passes into a purely chloritic or talcose mass.

It may be inferred from these facts that garnet is first converted into pyknotrope, and that this is converted into serpentine; so that there would be a series of products formed in this alteration, viz., garnet, pyknotrope, serpentine, chlorite, and talc.

Steatite with the form of garnet.—Alteration pseudomorphs of this kind have been found several times. Schlotheim* describes an entire druse consisting of steatite with the form of garnet. The steatite was, however, much harder than usual, so that it was perhaps more analogous to figure-stone. Mohs† describes a similar alteration. The small red garnet crystals, which occur scantily in the granite at Thiersheim, are converted into steatite near the mica that has suffered the same alteration.‡

The chemical features of the conversion of garnet into steatite will be treated of in chapter xli.

Talc with the form of pyrope.—At Meronitz, in Bohemia, and in the serpentine at Zöblitz, in Saxony, pyrope crystals occur, which have been converted into talc. These pseudomorphs are particularly distinct at the latter place. The numerous crystals of pyrope are much fissured, and the interstices filled with a soft earthy, talcose mass, or with white pearly laminæ of talc. The latter are sometimes in such quantity that the red pyrope is apparent only as isolated streaks.§ When the alteration is complete, an aggregate of talc laminæ take the place of the pyrope.||

* v. Hoff's Mag. für die Mineral, i, 157.

† Null's Mineral Cabinet, 1804, i, 548.

‡ Blum—Die Pseudomorphosen, 136.

§ Blum.—Ibid. p. 110, and Nachtrag, p. 67.

|| In the pseudomorphs belonging to the Edinburgh collection very few garnets are unaltered; some are partially, and most of them entirely, converted into talc.

Epidote with the form of garnet.—This pseudomorph has been treated of previously.*

Garnet with the form of vesuvian.—This pseudomorph is treated of in Chapter xxxiv.

In all the alterations to which garnet is subject, there is an elimination of lime; for chlorite, serpentine, steatite, and talc either do not contain this earth, or only traces of it, as in serpentine, where it may be supposed the alteration is not complete. Next to lime the iron is either wholly or partially eliminated, for chlorite alone contains it as an essential constituent; there is less in serpentine, and none or a mere trace in talc and steatite.

It is remarkable that no instance of the conversion of garnet into mica has yet been observed.† The conversion of wernerite into mica is sufficient to show that the presence of lime would not be an obstacle to this alteration. This is more remarkable because vesuvian, that so closely resembles garnet in composition, is capable of conversion into mica. It does not appear that there is any tendency to the introduction of alkalis into garnet, for it is only in three kinds that potash has been detected.

Decomposition of garnet.—Like all minerals containing considerable amounts of lime and protoxide of iron, those kinds of garnet which contain these bases are very liable to decomposition. The striated condition of some crystal faces,‡ their roughness, and the holes filled with products of decomposition, facilitate alteration, and are indicative of its commencement. The loss of lustre and hardness, the diminution of specific gravity, are further signs of alteration. Breithaupt§ describes a blackish-green aplome, which at one side was quite fresh and unaltered, giving sparks when struck with steel, while the other side had been converted into a softer mineral, the specific gravity of which was only 2.775, that of the unaltered aplome being from 3.65 to 3.85. The brilliant lustre of the uwarowite disappears during exposure, almost entirely, and the specific gravity is reduced to 3.418 or 2.969.

In the granite at Alabaschka, near Mursinsk,|| garnet crystals occur, which are blood-red and very transparent when quite

* See ante, p. 244.

† Perhaps the garnet crystals covered with mica, which occur in Aberdeenshire, may be alterations of this kind. The almandine previously mentioned, upon whose faces of union laminæ of mica occur, is in my possession. This mica is either a product of infiltration or of the alteration of garnet: I am disposed towards the latter view.

‡ See ante, p. 100.

§ Poggend. Annal. lx, 594.

|| G. Rose.—Reise.

unaltered, as is generally the case when they are completely imbedded, but when only partly imbedded they are black at the part which projects beyond the matrix. When attached to albite, the surface of this mineral is likewise black or covered with black dendrites.

G. Leonhard * communicated some interesting particulars relating to the disintegration of the garnet at Arendal. The outer crust is green, very much disintegrated, and at the interior is a nucleus of red colour, and unaltered. A tolerably large garnet crystal, with a rough corroded surface, and very much disintegrated, was filled inside with crystallized, acicular wernerite and epidote. The imperfect development of these minerals is unmis- takeable.

Besides the above-mentioned foreign substances† imbedded in garnet, there are others whose presence can be recognized only by the external characters, such as the dull colours which are often perceptible upon the faces of the finest crystals. Trolle-Wachtmeister ‡ attributes to garnet a remarkable tendency to include in its chemical constitution foreign substances. Karsten § supposes that the want of correspondence in the oxygen quotients of garnet, is owing to the presence of admixtures which cannot be separated.

The easy decomposition of garnet renders it unnecessary to show that these foreign admixtures which are not recognizable by the eye, are, for the most part, merely products of alteration.

Wiegleb || and Bucholz ¶ observed effervescence when the calcareous garnet was immersed in hydrochloric acid; they found it to contain from 4 to 4·25 per cent. carbonic acid and water. Trolle-Wachtmeister ** likewise observed effervescence in several specimens of calcareous garnet, and found that the acid dissolved some lime. He pointed out that the oxygen quotients of several garnets, analyzed by him, were less than that corresponding with the theoretical composition. This was especially remarkable in the iron garnet of Klemetsaure, in Norway, the oxygen quotient of which was only 0·6 instead of 1. The results of several repetitions of his analyses do not present any considerable differences.

* Jahrbuch für Mineralog., 1841, p. 75.

† See ante, p. 286.

‡ Loc. cit.

§ Loc. cit.

|| Crell's Chemische Ann. 1788, i, 201.

¶ Gehlen's neues Journ. iv, 172.

** Poggend. Annal. ii, 1.

v. Kobell* likewise pointed out this discrepancy between theory and the results of analysis. It is evident that the oxygen quotient would be less in proportion as the bases were removed by decomposition, while the silica remained. But if carbonic acid were the decomposing agent, the bases alone would be removed and not the silica. If, on the contrary, the decomposition is effected by alkaline carbonates,† the silicate of lime would be replaced by alkaline silicate, and the relation of the bases to the silica would not be altered. This kind of alteration may have taken place in those garnets which contain from 0·59 to 2·35 per cent. of potash, and more especially since they are calcareous garnet. However, since there are only three instances of garnet containing potash, among the numerous analyses of garnet that have been made, this kind of alteration would appear to be rare. Near Beaujeux,—Depart. Rhone—veins of iron ore occur in a very thick bed of garnet.‡ Near Arendal, likewise, garnet occurs in the rocks adjoining the beds of iron ore, and sometimes in cavities within the latter.§ It is probable that these iron ores originate from decomposed garnet, and if this is the case it would be in accordance with the very considerable loss of bases evident in the garnet of Klemetsaure.

The presence of lime in combination with carbonic acid in many garnets has hitherto been regarded as accidental. But if it had been borne in mind that those minerals and rocks, in which there is perceptible admixture of calc-spar, or which effervesce with acids, are, for the most part, such as contain silicate of lime, the origin of this carbonate of lime would long since have been referred to the decomposition of silicate of lime.

Although the carbonate of lime mixed with garnet is mostly a product of decomposition, there are instances in which it would appear to have been in existence before the garnet. Blum sent me a description of a garnet, in which only a crust about the thickness of a sheet of paper consisted of garnet, while the remaining portion was calc-spar. J. Roth|| found in the micaceous limestone of Predazzo, crystals of green garnet which appeared perfectly unaltered, although there was only a thin crust of garnet substance, and the remaining portion consisted of granular, splintery garnet mixed with carbonate of lime. Since the faces

* Kastner's Archiv, x, 23.

† English edition, i, 8.

‡ Ebelmen. — Berzelius's Jahresbericht, xxvi, 367.

§ Weibye—Archiv. für Mineral. &c. xxii, 480.

|| Zeitschrift der deutschen geol. Gesellschaft, iii, 147.

present a perfect lustre without any signs of disintegration, he conjectures that in this case at least the carbonate of lime was older than the garnet, and that it had prevented the crystallization of the garnet. In the Berlin collection of minerals, I found a specimen of brown garnet with calc-spar disseminated throughout the entire mass, although the faces were quite perfect. At Arendal likewise, garnet crystals occur which are filled with calc-spar.*

Since garnet can have been formed only in the wet way, it may be supposed that at the time of its formation it surrounded calc-spar, and that the water from which the garnet substance was deposited, afterwards removed a portion of the carbonate of lime, thus leaving room for further deposition of garnet. This is especially probably where the garnet occurs in granular limestone as is so frequently the case.

CHAPTER XXXIV.

VESUVIAN—IDOCRASE.

THE remarks already made as to the action of acids upon garnet are likewise applicable to vesuvian. Fuchs† found that after ignition it was perfectly decomposed by acids. Magnus was unable to decompose vesuvian that had not been melted, even when the very fine powder was digested with sulphuric acid; but after having been melted, it was dissolved readily by cold hydrochloric acid with considerable evolution of heat. By melting the mineral the specific gravity is reduced nearly one-seventh.‡

Occurrence.—In serpentine, granular limestone, dolomite, diorite, syenite, micaceous schist, chloritic schist, gneiss; in deposits of metalliferous ores, and in the masses thrown out from Monte Somma during the older eruptions. It occurs either in isolated crystals or in drusy cavities, and upon fissures.

Vesuvian has but little geological importance, for it is neither an essential constituent of any rock, nor does it occur so abundantly in any rock as to produce an alteration of character, as is the case with garnet in micaceous schist. The occurrence of vesuvian imbedded in calc-spar and accompanied by green augite,

* Weibye.—Archiv. für Mineral. xxii, 480.

† Schweigger's Journ., xxiv, 376.

‡ Magnus.—Poggend. Annal. xxii, 391.

as at Monzoniberg in the Tyrol, where it constitutes a large mass in the diorite, is probably rare.

Vesuvian is frequently associated with garnet, together with calc-spar, epidote, chlorite, magnetic iron ore and other minerals. At the Beresowaja Gora it occurs imbedded in compact white garnet.* It frequently constitutes the interior portion of garnet crystals, or the garnet appears as the nucleus of vesuvian crystals.† Upon the vesuvian crystals from Siberia there are small, opaque, garnet-shaped granules of greenish and yellowish-white colour, which are sometimes slightly attached and sometimes deeply imbedded. Near Bermsgrün, vesuvian crystals occur, some of which are hollow, others with a conchoidal structure; they are imbedded in the limestone rock with wollastonite, and when broken present alternate layers of limestone and vesuvian.‡

J. Roth § describes vesuvian from Predazzo, in which small particles of calc-spar are imbedded. Externally they appear quite unaltered, so that it is not probable that the calc-spar is a product of the decomposition of the vesuvian. However, the prior existence of the calc-spar would exclude the possibility of the vesuvian being formed in any other than the wet way.

Composition.—Vesuvian consists of silicates of alumina, peroxide of iron, lime, and magnesia. The amount of alumina varies between 17·23 and 10·51 per cent., the peroxide of iron between 9·03 and 2·16 per cent., the lime between 37·41 and 27·70 per cent., the magnesia between 10·6 and 1·54 per cent. It almost always contains a small amount of potash, from 0·25 to 1·32 per cent., and sometimes protoxide of manganese.

The composition of vesuvian has hitherto been considered identical with that of garnet, although not one of the specimens analyzed by Klaproth, Karsten, v. Kobell, Magnus, etc., correspond with garnet in the oxygen ration of the monoxides and the sesquioxides. According to Hermann's || analyses of four specimens of Russian vesuvian this proportion is = 3 : 2.

Rammelsberg ¶ analyzed thirteen specimens of vesuvian from various localities. Even in those which contained a large amount of iron he was often unable to find any protoxide. He does not, however, infer that it was entirely absent, for in the vesuvian

* G. Rose.—Reise, ii, 131.

† G. Leonhard.—Jahrbuch für Mineral. 1841, p. 75.

‡ Freiesleben's Mag. vi, 112, and Naumann.—Erläuterungen, ii, 237.

§ Loc. cit.

|| Journ. für prakt. Chemie. xliv, 193.

¶ Poggend. Annal. xciv, 92 et seq.

At many places the mica extended into the interior, so that a crystal broken in two presents a mixture of vesuvian and mica, the former being porous. It is evident that in this instance the mica originated from the vesuvian, although the alteration has not extended to the entire mass of the vesuvian.

Rammelsberg states that the vesuvian from the Mussa-Alp, in the Ala Valley, presents, at many parts, very small greenish scales of chlorite or mica, imbedded in the mass of the mineral. Probably these are likewise products of alteration.

The colour of the mica described by Blum renders it probable that it was potash-mica; but as there has not been any analysis published, I can only give that by v. Kobell,* of the vesuvian from Monzoni, I.

	I.	II.	
		a.	b.
Silica	37.64	37.15 ...	39.70
Alumina	15.42	13.44 ...	12.90
Protoxide of iron	6.42	Fe ² O ³ 6.47 ...	7.40
Protoxide of manganese ....	...	0.95 ...	0.40
Lime	38.24	36.46 ...	36.86
Magnesia ...	...	2.87 ...	3.18
Potash ...	...	0.93 ...	not estimated
	97.72	98.27	100.44

If the vesuvian containing the laminæ of mica had the same composition as this specimen, it is possible, since there is no magnesia present, that the formation of mica was effected by the decomposition of a part of the silicate of lime by carbonate of potash,† while the remainder was decomposed by carbonic acid; so that silicate of potash would have been formed, and the lime removed as carbonate, while the silica of the silicate of lime remained.

II. Vesuvian from the Ala Valley, with the laminæ of mica or chlorite; analyzed, by Rammelsberg: *a* represents vesuvian that had not been melted; *b* the melted mineral, previously digested with dilute hydrochloric acid, washed, dried, and slightly ignited. The loss by fusion amounted to 3 per cent.; and the mass became dark-colored at parts.

Since the composition of the vesuvian represented by II is

* Kastner's Archiv. vii, 399.
† English edition, i, 8.

very similar to I, the formation of the mica laminæ may be supposed to have taken place in the same manner. Potash-mica sometimes contains as much magnesia as II.

Although these remarks are merely conjectural, there can be no question that vesuvian having the composition I and II, would be susceptible of a conversion into mica, and the almost constant presence of potash seems to indicate a tendency to such an alteration.

Steatite with the form of vesuvian.—Blum * states that some specimens of vesuvian from the Alpe della Mussa, present traces of incipient alteration. They have a slight fatty lustre, and are rather soft, so that at some parts they may be scratched with a knife. The vesuvian from the government Oerenburg is quite soft at the surface, sometimes full of cracks, between which the alteration has advanced, so that in some instances a mixture of vesuvian and a steatitic substance, presenting the form of vesuvian, has been produced. He also observed the conversion into steatite, in the vesuvian of Monzoni.

The chemical features of this alteration are the same as in the conversion of garnet into steatite, and in most respects the phenomena presented by vesuvian are the same as those more fully described in the case of garnet. There is reason to believe that further examination will bring to light conversions of vesuvian into chlorite and serpentine. Perhaps the occurrence of vesuvian in serpentine, and its association with chlorite, as at Monte Somma, are indicative of such alterations. Klaproth † observed in the analysis of this vesuvian that delicate greenish-white laminæ of chlorite and mica were separated while washing the powdered mineral.

Wernerite and garnet with the form of vesuvian.—Sillem ‡ describes this pseudomorph as occurring at Egg, in Norway; the somewhat large vesuvian crystals consist of a mixture of wernerite with a smaller proportion of garnet. They are rough and drusy, with cavities inside. At some places small wernerite crystals occur upon them, and at others garnet crystals.

Analyses of the vesuvian from Egg have been published, but as it is not known whether the composition of the pseudomorphous wernerite corresponds with I or II, § the characteristic features of the decomposition cannot be pointed out with certainty. So

* Die Pseudomorphosen, p. 137.

† Beitrage, ii, 29.

‡ Blum.—Nachtrag, ii, 46.

§ See ante, p. 247.

much, however, is certain, that portions of the lime, magnesia, and protoxide of iron are separated from the vesuvian. The cavities in these pseudomorphs render it probable that the alteration is effected merely in this way, and that the relative proportion of the alumina has been increased to the amount present in wernerite or meionite. The oxygen quotient of meionite is 1, like that of vesuvian, but the amount of alumina is much larger than in the latter mineral.

Decomposition of vesuvian.—Vesuvian appears to be generally less liable to disintegration than garnet. G. Leonhard* has described some interesting phenomena of decomposition, presented by the vesuvian at Arendal. This frequently appears with its primitive form as the nucleus of other vesuvian crystals, which are derivatives of it. The outer crust is much disintegrated, frequently bleached, while the nucleus is quite fresh and bright-colored.† There is often an appearance of several crystals being inclosed within each other. Thus the nucleus is often surrounded by a concentric circle of derivative forms, and the surface of the mineral is duller, rougher, and has less lustre the nearer they are to the outer crust. In one specimen this outer crust is rent, and cemented together by a fresh vesuvian crystal. This is an evident proof that the formation of the crystal had been resumed at a subsequent period, and this cannot be supposed to have taken place in any other than the wet way. ‡

* Loc. cit.

† In specimens of garnet from the Alpe della Mussa, in Piedmont, the opposite case may be recognized. Here the crystal presenting the primitive form is of a dark reddish-brown colour, and is disintegrated, but surrounded by derivative forms which are bright-red, of conchoidal texture and considerable lustre.

‡ German edition, ii, 506.

position, which if it had been present would have been dissolved in the first treatment with acid.

In another experiment with similar augite crystals from the lake of Laach, hydrochloric acid extracted from the fine powder 3·15 per cent. of substance which consisted of—

Silica	....	....	....	....	0·10
Alumina	....	....	....	....	0·41
Protoxides of iron and manganese	....				1·56
Lime	....	....	....	....	0·98
Potash and soda	....	....	....	....	0·10

The residue likewise contained alkalies. The crystals were unequally altered, the edges and corners rounded, the faces without lustre, rough, and presented small hollows and cracks here and there; the uneven surfaces of fracture were bright. No foreign mineral could be detected in the hollows by the aid of the magnifying glass.

According to Heidepriem* powdered diopside is somewhat considerably acted upon when digested for several days with hydrochloric acid. In one experiment 11·23 per cent. was decomposed, and the composition of this part was identical with that of the mineral.

After being melted, augite is not acted upon by acids more readily than in its normal state.

Occurrence.—The common augite, both in crystals and compact masses, is the most important of the different kinds of augite, in a geological point of view, because it occurs most frequently, and in many of the more considerable rocks. It is an essential constituent of basalt, dolerite, augitic porphyry, melaphyr, basaltic amygdaloid, and the lava both of active and extinct volcanoes—Vesuvius,† Etna, and Stromboli; the environs of the lake of Laach, the Eifel, Auvergne, Teneriffe, Bourbon, etc. Well developed augite crystals are frequently thrown out in large quantities from volcanoes; they likewise occur in volcanic sand from some of the eruptions of Vesuvius and the crater of Stromboli, as well as in the masses thrown out from Monti Rossi, formed in 1669 at Etna.‡ It also occurs as well developed crystals in volcanic and basaltic tuff.

* Zeitschrift der deutschen geolog. Gesellschaft, ii, 141.

† Breislakite, which occurs in small hair-shaped crystals in some lavas at Vesuvius and at the Campo di Bove, near Rome, is identical in form and composition with augite.—E. Chapman.—Phil. Mag. Ser. 4, ii, 21.

‡ Pilla—Jahrbuch für Mineral. 1846, p. 341.

The formation of augite in volcanic rocks has already been treated of.*

Augite likewise occurs as a peculiar rock in the augite rock at the Lherz lake, and in the Vicdessos Valley in the Pyrenees. Lastly, it is met with upon beds in the older rocks at Arendal, in Norway, in the gneiss of Wermeland, and Bolton, U. S., etc.

Diopside occurs in crystals an inch long upon lodes in chloritic schist at Achmatowsk in the Ural, most frequently associated with garnet and chlorite, to which it is attached. Consequently it is of later formation than these minerals, and can have been formed only in the wet way, since the chlorite contains 12·6 per cent. water. In the Erzgebirge it occurs associated with the same minerals, and at Schwarzenstein with these and hornblende, upon fissures in hornblende rock. Its occurrence in serpentine at the Alpe della Mussa, and the Fichtelgebirge; in granular limestone at Straschkau and Heinzengraben in Moravia, and near Postua and Biella, where augite crystals occur in nests of marble; † in the dolomitic limestone of the state of New York, Westchester, and Putnam, ‡ is decisive evidence that this mineral has not been formed by fusion, because these rocks were formed or altered in the wet way.

Malacolite likewise occurs very frequently in granular limestone and in calc-spar. In the fissures, which traverse the micaceous schist of the Erzgebirge in all directions, it occurs with sahlite, diopside, garnet, egeran, chlorite, hornblende, actinote, prehnite, axinite, mica, asbestos, quartz, schiefer-spar, fluor-spar, blende, copper-pyrites, blue carbonate of copper, malachite, and oxide of manganese. Upon the bed of magnetic iron ore in the Age mine, in Sweden, malacolite is sometimes imbedded in quartz, and it sometimes occurs in drusy cavities. § At Sahla, malacolite is generally imbedded in galena, less frequently in calc-spar; indeed it appears to occur only associated with, or near galena; so that its formation may be, in some sort, dependent upon that of galena. || It is worth remarking, that angular fragments of granular limestone are frequently imbedded in galena.

* See ante, p. 94.

† Studer.—*Geologie der Schweiz*, i, 298.

‡ Reports of the meetings of the Association of American Geologists. Boston, 1843, p. 251. Augite—common?—occurs in North America very abundantly in limestone; as at Twopounds, where the crystals are six inches long and ten inches diameter.—*Jahrbuch für Mineral*, 1849, p. 809.

§ G. Suckow.—*Die bedeutendsten Erz und Gesteinslager im Schwedischen Urgebirge*. 1831, p. 41.

|| Daubrée.—*Skandinaviens Erzlagerstätten*. German translation by G. Leonhard, p. 42.

In the Berlin collection of minerals I saw sahlite crystals imbedded in galena and blende; one of them was rent, and the space filled up with blende; so that it was evidently of later formation than the sahlite. In another specimen there was calc-spar, which is undoubtedly of later formation than either galena or blende. One calc-spar crystal was cracked, and the space filled with new calc-spar; so that calcareous water must have flowed through these beds long after the other minerals had been formed.

Coccolite occurs, like both the previous kinds of augite, in granular limestone; and upon deposits of ore in Sweden and Norway; and in small masses throughout all deposits of iron ore.*

F. Sandberger describes a large augite crystal, in which there is disseminated throughout the entire mass a mineral which he considers to be olivine in a state of incipient decomposition.

In a letter to me, Blum describes small augite crystals, in analcime and comptonite, which occur very well developed in drusy cavities of the rock called analcimite, in the Cyclopean Islands.† It cannot be supposed that these augite crystals have been formed in any other than the wet way.

It would be superfluous to bring forward further proofs of the formation of these augite crystals in the wet way; and, in the above instances, no other mode of formation can be imagined.‡

Nevertheless, the possibility of the formation of augite by fusion cannot be questioned. Mitscherlich§ frequently found, among the crystallized slags from metallurgical operations, substances with the form of augite, but never that of hornblende. He and Berthier obtained a white augite by melting together silica, lime, and magnesia, in a carbon crucible, by the heat of a porcelain furnace. The mass became perfectly liquid, presented the cleavage of augite, and a cavity was lined with very perfectly developed augite crystals. They were, however, unable to obtain hornblende crystals, even when the proportion of the ingredients was altered. G. Rose found that when actinote is melted in a platinum crucible it yields, on cooling, augite crystals.

* Weibye.—Archiv. für Mineral. xxii, 472.

† Blum also mentions the following minerals as having been observed to contain imbedded augite: sauidine, nepheline, sodalite, hauyn, meionite, vesuvian, melilite, and hornblende.

‡ German edition, ii, 528 et seq.

§ Ibid. p. 543, et seq.]

A crystallized slag, described by Hausmann,* consisted of:—

Silica	....	....	....	54.70
Alumina	....	....	....	1.54
Protoxide of iron		....		0.08
Protoxide of manganese	....			1.68
Lime	....	....	....	23.56
Magnesia	....	....	....	15.37
Soda	....	....	....	1.93
Potash	....	....	....	1.15
				<hr/>
				100.00
O. Q.	....	....	....	0.511

This oxygen quotient corresponds to that of augite † as nearly as could be expected ; therefore, there is both chemical and mineralogical evidence of the formation of augite by fusion. Moreover, the presence of alkalies shows that they may be substituted for alkaline earths to some small amount. It may be, that minute quantities of alkalies are likewise present in native augite ; and they are not indicated in the results of analysis only because they have not been sought for. It is, in this respect, very desirable that those analyses should be repeated in which there is any considerable deficiency.

Composition.

A.—AUGITE WITHOUT ALUMINA.

The different kinds of augite will be arranged according to the bases they contain in largest amount.

Lime-magnesia augite.

	Analyzed by	O. Q.
I. Blueish-green augite from Pargas....	Nordenskiöld ‡	0.528
II. Augite from Långbanskyttan	Reutersköld §	0.525
III. Diopside from Tammare in Finland....	Bonsdorff ||	0.514
IV. Diopside from the Fassathal	Wackenroder ¶	0.526
V. White malacolite from Orrijerwi in Finland	} H. Rose**	.... 0.528

* Nachrichten der Gesellschaft der Wissensch. zu Göttingen, 1851.—
F. Sandberger—Poggend. Annal. lxxxij, 457—describes augite crystals upon
slags from an iron furnace. In fissures within the furnace brownish-grey prisms,
were found, elongated in the direction of the principal axis, analogous to diopside
and sahlite.

† See p. 312.
‡ Schweigger's Journ., xxxi, 427.
§ Berzelius's Jahresbericht, xxv, 362.
|| Schweigger's Journ. xxx, 159.
¶ Kastner's Archiv. xiii, 97.
** Schweigger's Journ. xxxv, 93.

Analyzed by O. Q.

VI. Malacolite from Långbanskyttan } H. Rose* 0.514
in Wermeland

The full results of the analysis of the following specimens of augite are given, because, by comparing them with the results obtained in the analysis of unaltered augite, the course of the decomposition to which these minerals are principally subject, may be traced.

	VII.	VIII.	IX.	X.	XI.	XII.
Silica	55.82	57.40	54.86	60.65	58.08	58.08
Lime	23.01	23.10	23.57	4.97	11.24	9.89
Magnesia	16.99	16.74	16.49	25.20	with MnO 22.28	24.22
Peroxide of iron	2.16	0.20	FeO 4.44	4.18	5.30	4.24
Oxide of manganese	1.59	...	0.42	0.79	...	0.68
Alumina ... ..	...	0.43	0.21	4.20	0.47	0.11
Water ... ..	...	...	...	...	8.11	8.11
	99.07	97.87	99.99	99.99	100.48	100.38
O. Q.	0.496	0.447	0.502	0.392	0.439	0.442

Analyzed by

VII. Yellowish malacolite from Långbanskyttan H. Rose.†

This mineral has the normal composition.

VIII. White malacolite from Tjötten, } Trolle-Wachtmeister.‡
in Norway

The surface of this mineral is here and there covered with an ochre-brown film. When heated, it becomes dark-grey, in a closed vessel almost black; and again becomes white when intensely heated. In one specimen, granular limestone was imbedded in the direction of the longitudinal fracture; it effervesced copiously with acids. This mineral was, therefore, in a state of decomposition; and bases, peroxide of iron and carbonate of lime, had been separated, as is evident from the low oxygen quotient. The blackening, when heated, shows the presence of organic substance. There could not have been much hydrated peroxide of iron formed, because no water was evolved when the mineral was ignited.

IX. Greenish sahlite from Sahla, in Sweden.§

It gave sparks when struck with steel; its normal composition indicates an unaltered state.

* Schweigger's Journal, xxxv, 94.

† Ibid. p. 86.

‡ Ibid. xxx, 334.

§ Ibid. xxxi, 100.

X. Sahlite from the same locality.*

When ignited, it gave off 4·1 to 4·9 per cent. water, with empyreumatic odour; other specimens of sahlite never lost so much as 1 per cent.

XI. Sahlite from one end of the same specimen.†

XII. Sahlite from the other end.‡

These four analyses were made by H. Rose.

The minerals represented by X, XI, and XII resembled in colour that represented by IX; but their lustre was much less, and the hardness so little that they could be scratched with the nail. When heated they became black and white again in the open fire. These characteristics, as well as their lower oxygen quotients, show that the minerals are decomposed.

Consequently the alteration of sahlite consists in the reduction of the amount of lime, while that of magnesia is increased. Water containing carbonate of magnesia decomposed the silicate of lime, and removed the lime as carbonate, while silicate of magnesia was deposited in its place.‡ This alteration was effected, as is generally the case, by introduction of water and formation of hydrated silicate of magnesia. The composition of the minerals represented by XII, XI and X especially, approximates very closely to that of steatite. Supposing the residual lime to have been displaced by magnesia, the substance would have the normal composition of steatite. It would appear from the relatively increased amount of silica, that in other respects the lime removed was more than equivalent to the magnesia introduced. The compositions of V and VI show that the alteration may be unequal at different parts of a crystal, § VI being evidently in a further advanced state of decomposition than V. Although pseudomorphous minerals present countless instances of such diversities of alteration, it is still highly interesting to recognize this fact by means of chemical analysis in a mineral which probably did not present any difference in appearance at the two ends. The cleavage of this mineral had not entirely disappeared.||

* Schweigger's Journal, xxxi, p. 102.

† Ibid. p. 105.

‡ English edition, i, 13, No. 16.

§ See ante, p. 104.

|| G. Rose—Poggend. Annal. lxxx, 126.

Lime-protioxide of iron augite.

	Analized by	O. Q.
XIII. Hedenbergite from Tunaberg in Södermanland	} H. Rose*	.... 0·501
XIV. Black augite from Arendal		
XV. Black crystallized augite from Taberg in Wermeland	} H. Rose†	.... 0·437
XVI. Reddish - brown malacolite from Dageroe in Finland		
XVII. Augite from Nordmark	.... Funk ||	.... 0·485

Lime-protioxide of manganese augite.

XVIII. Red bisilicate of manganese from Långbanskyttan	} Berzelius¶	.... 0·482
XIX. Similar mineral from Algiers		
XX. „ „ Piedmont	.... Ebelmen**	.... 0·530
	.... Ebelmen**	.... 0·507

Lime-magnesia-protioxide of iron augite.

XXI. Green malacolite from Björmy- resoeden in Dalecarlia	} H. Rose††	.... 0·481
XXII. The same mineral		
XXIII. „ „	.... d'Oksson‡‡	.... 0·456

In these analyses the iron was calculated as protoxide although there is no doubt that some portion was peroxide; therefore the oxygen quotient of those specimens of augite which contain much iron must have been estimated too low. These ferruginous augites present the lowest oxygen quotients, while those from I to VII and IX with little iron have the highest oxygen quotients. It would be very difficult to determine the average oxygen quotient from the preceding values, even when excluding the ferruginous augites and those represented by VIII, X, XI and XII, which are obviously altered; for it still remains questionable whether

* Loc. cit. p. 97.

† Journ, für prakt. Chemie. xxxiv, 236.

‡ Loc. cit. p. 99.

§ Afhandl. i. Fysik, ii, 208.

|| Berzelius's Jahresbericht, xxv, 362.

¶ Schweigger's Journ. xxi, 254.

** Comptes rendus, xx, 1418.

†† Loc. cit. p. 98.

‡‡ Schweigger's Journ. xxx, 351.

the other specimens of augite have experienced a loss of bases, and to what extent this may have taken place and brought about a reduction of the oxygen quotient. However, there would probably be little deviation from the truth in fixing the normal value of the oxygen quotient at 0.5. When it is remembered that for these analyses the most perfect specimens of augite were selected there is good ground for the inference that altered augite occurs far more frequently than the unaltered mineral.

With regard to the specimens of malacolite, XXI to XXIII it must be observed that those analyzed by H. Rose are almost exactly alike in hardness, colour, transparency, streak, and lustre, that they were from the same locality and nevertheless showed differences in the amounts of their constituents amounting to 3 per cent. Therefore no doubt can remain that these specimens have lost some portion of their bases, and it would appear that the lime-magnesia-prot oxide of iron augite is especially liable to decomposition.

B.—ALUMINOUS AUGITE.

The theoretical representation of the chemical constitution of these augites has been a matter of considerable difficulty. As alumina is not isomorphous with the other bases present in augite, it was conjectured that it might be an electronegative constituent, and replace part of the silica.

	Analized by	O. Q.
XXIV. Augite crystals from Zigo- lonberg in the Fassathal	}	0.589
XXV. Four fragments of a crystal from the Gillenfeld Maar in the Eifel	}	0.619 0.688 0.658 0.632
XXVI. Augite crystals from the Rhone Mountains	}	0.628
XXVII. Augite crystal from Etna	....	0.587
XXVIII. „ „ Vesuvius	....	0.606
These eight analyses are by Kudernatsch.*		
XXIX. Augite from Frascati	.... Klaproth†	0.608
XXX. Augite from Pico in the Azores	} Hochstetter‡	0.505
XXXI. Augite from Ostheim	.... C. Gmelin§	0.505

* Poggend. Annal. xxxvii, 577 et seq.

† Beiträge, v, 166.

‡ Journ. für prakt. Chemie. xxvii, 375.

§ Jahrbuch für Mineral. 1840, p. 549.

	Analyzed by	O. Q.
XXXII. Brown augite from Par- gas	Nordensköld*	0.546
XXXIII. Augite from lava blocks at the Weinfeld Maar in the Eifel	Kjerulf†	... 0.683
XXXIV. Augite out of the lake of Laach, somewhat altered	Bischof‡	... 0.511
XXXV. Augite from the same locality	Breidenstein‡	0.597
XXXVI. Augite from Schima in Bohemia	Breidenstein‡	0.576
XXXVII. Augite from Härtlingen....	Rammelsberg‡	0.728
XXXVIII. Augite from Teneriffe	Deville§	... 0.605
XXXIX. Hudsonite from Cornwall, Orange County, New York	Brewer||	... 0.905
XL. The same mineral	Beck¶	... 0.919
XLI. Brownsalite from Fürsten- berg	Fröhlich**	... 0.529

Excluding those specimens of augite for which the oxygen quotient is less than 0.6 or above 0.7, as having been evidently altered to some extent, still the other specimens do not present the same oxygen quotient, and this is the case even with fragments of the same mineral, to such an extent that there does not appear any possibility of deducing from these results a normal value for the oxygen quotient. It might be assumed that the highest oxygen quotient = 0.667 is nearest to the normal value, because the mineral it represented would have experienced the least loss of bases; but the minerals represented by XXXVII, XXXIX and XL, show that the alteration may consist in loss of silica.

Kudernatsch conjectures that the discrepancy presented by the analytical results is owing to the presence of some extraneous substance. Indeed augite crystals are very rarely quite fresh and homogeneous at the interior; but more frequently present small

* Bidrag, p. 76.

† This analysis was made in my laboratory. It is possible that some fragments of hornblende were mixed with the mineral.

‡ Rammelsberg.—Suppl. 5, p. 60.

§ Etudes géol. sur les Iles de Ténériffe. Paris, 1848.

|| Amer. Journ. of Science, ix.

¶ Minerals of New York, p. 405.

** Rammelsberg.—Suppl. 5, p. 62.

fissures and disintegrated patches. Thus the augite crystals of Zigolonberg, when broken, present fissures filled with ferruginous clay. It is evident that this augite must have lost a portion of its protoxide of iron, and probably some of its lime also. Although the purest pieces were selected for analysis, it is possible that they may have experienced a partial loss of bases, and this would account for the considerable difference between the amount of bases found, and that indicated by calculation. Kudernatsch points out that the augite from the Gillenfeld Maar differs in composition at different parts, and the same circumstance was observed by H. Rose in sahlite and malacolite. Rose likewise observed that between the laminæ of the large augite crystals especially, there were frequently distinct admixtures, and particles of the surrounding rock which could be recognized by the naked eye. This might also influence the analytical results.

I have calculated the oxygen quotients of the aluminous augites upon the assumption that the alumina is an electronegative constituent.* In this case the oxygen quotient approximates to that of the augite without alumina = 0.5; so that the same oxygen quotient may be assigned to both classes of augite. But then the small amounts of alumina present in many of the latter class of augites must be regarded as an electronegative constituent. Lastly, the alumina may be regarded as partly an electronegative and partly an electropositive constituent. But the admission that the analyses hitherto made, although very numerous, do not furnish data sufficient for the determination of the normal oxygen quotient, would, perhaps, be preferable to any one of these assumptions.

Alteration of augite.—Taking 0.5 as the oxygen quotient of the augite without alumina, and 0.66 as the approximative value of the oxygen quotient of the aluminous augite, it will be seen that the oxygen quotient is considerably less than these values in both classes of augite—VIII, X, XI, XII, XV, XXX, XXXI, XXXIV, XLI—but that in the second class the oxygen quotient is seldom much above the normal value. Consequently alteration, attended with loss of bases, takes place in the minerals of both classes, while the alteration of the minerals belonging to the second class consists chiefly in loss of silica.

Hornblende with the form of augite.—Under the name of uralite G. Rose† describes crystals, which have the form of augite with the

* German edition, ii, 522, et seq.

† Reise nach dem Ural, ii, 347 et seq. — See also Blum.—Die Pseudomorphosen, p. 154 et seq.

structure and cleavage of hornblende. He found them first in the Ural, where it is very frequent; subsequently however it was found in the augitic porphyry, near Predazzo, in the Tyrol; in detritus at Mysore, in India; in the West Indian Islands; and at Tunguragua in Quito. The Corsican smaragdite, which occurs as crystals or crystalline granules in saussurite, is, according to Rose, identical with uralite.* In the Ural, this mineral occurs only as crystals imbedded in a peculiar variety of augitic porphyry, and with the ordinary crystal form of common augite, as well as twin combinations of this form. But although the form of uralite corresponds with that of augite, the structure does not, the crystals are cleavable only in two planes, similar to the cleavage of hornblende.

Sometimes uralite in augitic porphyry is associated with augite, but then it is always symmetrically blended with it. The uralite crystals are of unequal size. The smaller ones have at the interior the ordinary appearance of uralite; the larger ones have a nucleus of augite, which has a grass-green colour and vitreous lustre, while the exterior portion is blackish-green. This nucleus has all the appearance of the interior of the augite crystals occurring alone in augitic porphyry at other localities; but it is always symmetrically blended with the surrounding uralite. The planes of cleavage in augite and in uralite are situated in a zone, and are parallel to the external faces. In the larger crystals the augite nucleus is sometimes very large, occupying almost the whole of the crystal, while the uralite constitutes only a thin dark-colored crust around it. In other crystals, particularly the small ones, this nucleus is small, and often appears only as a light-colored speck in the midst of the blackish-green mass; sometimes it is altogether wanting.

In augite crystals from Arendal, G. Rose recognized a gradual transition from the lustrous substance at the exterior, to the interior, which did not present any vestige of augite. Therefore little probability attaches to the opinion that augite and hornblende substance are blended together; it is much more likely that there is a conversion of augite into hornblende, and that uralite is a pseudomorphous hornblende after augite. This pseudomorph is one of the few which have cleavage.

The hornblende crystals, which completely cover the augite crystals, are filled inside with ferruginous calc-spar, and effervesce with acids. This has often been decomposed, and the cavities

* Poggend. Annal. xxxi, 610.

first stage of alteration, in which only the relative proportion of the lime and magnesia is altered; for in the aluminous augite the lime always preponderates over the magnesia, and in the aluminous hornblende the magnesia preponderates over the lime with very few exceptions. At least, there is not one among all the specimens of aluminous hornblende that have been analyzed, in which the amount of magnesia is less than that of lime.

The conversion of augite into hornblende is accounted for most simply by the reaction between bicarbonate of magnesia and silicate of lime.* The removal of the lime as carbonate is shown by the ferruginous calc-spar already mentioned,† which fills the hornblende crystals that have been formed from augite. According to G. Rose,‡ the uralite crystals in the augitic porphyry near Pyschma leave smooth impressions in the rock, which, at these places, is generally covered with a thin crust of brown-iron ochre.

Therefore a portion of the protosilicate of iron is likewise decomposed, and hydrated peroxide of iron separated. A comparative analysis of augite, and of hornblende originating from it, would probably indicate a diminution of the amount of iron.

The specific gravity of augite varies between 3.195 and 3.525; that of hornblende between 2.931 and 3.445; so that the specific gravity of augite is generally greater than that of hornblende. Hence there is a possibility of the conversion of the former into the latter by loss of constituents, and without alteration of the volume.

According to G. Rose,§ hornblende has been formed by gradual cooling, augite by rapid cooling; but the association of augite and hornblende, pointed out by F. Sandberger, indicates a simultaneous formation of these minerals, and is opposed to the opinion entertained by G. Rose.

I am disposed to agree with G. Rose in the opinion that the hornblende in basalt is a product of the alteration of the augitic matrix. But this alteration can take place only in the wet way; and Rose's observation that in the crystals at Arendal, the alteration is facilitated by fissures and cracks, and extends rapidly into the interior of the mass, is not unimportant in this respect, for it is well known that water penetrates even the finest cracks, but there is no reason for supposing that the action of heat would be

* English edition, i, 13, No. 16.

† See ante. p. 315.

‡ Reise, etc., i, 285.

§ Poggend. Annal. xxii, 336.

|| German edition, ii, 543, et seq.

exercised along the cracks more than through the mass itself. It cannot be objected that the hornblende in basalt does not occur with the form of augite, for when an amorphous mass of augite is converted into hornblende this mineral will present its proper crystal form.

Conversion of augite into asbestos.—The Green augite crystals from the Brozzo Valley, in Piedmont, present, according to Blum,* a total conversion into asbestos; and the alteration may be traced from beginning to end. At first the colour, lustre, and transparency of the crystals is altered; a fine web of asbestos is formed upon the surface; and, finally, the whole is converted into a silky bunch of asbestos, the form being lost at the same time. Some of the bunches of asbestos lie here and there upon the rock, which consists of a mixture of somewhat granular green augite, with magnetic iron ore. The presence of this latter substance shows that in the alteration, magnetic oxide of iron is separated.

A specimen from the Val Locana, in Piedmont, likewise presents alteration of the augite crystals into a confused mass of fibrous asbestos, similar to mountain cork; the sharpness of the corners and edges was quite lost; and the surface of the crystals was rough, uneven, and drusy. On breaking the crystals, the asbestos appeared to extend some distance into the mass; and at the centre there was a recognizable nucleus of green augite.

	I.	II.	III.	IV.	V.	VI.
Silica	54.50	55.85	55.87	58.20	57.98	57.50
Alumina	1.10	0.56	....	0.14	0.58	....
Protoxide of manganese	....	...	1.12	0.21		
Protoxide of iron	3.00	5.22	4.31	3.08	6.32	3.88
Lime	21.41	11.66	17.76	15.55	12.95	13.42
Magnesia	18.96	23.99	20.33	22.10	22.38	23.09
Water	1.19	2.15	....	0.14	....	2.36
	100.16	99.43	99.39	99.42	100.21	100.25
O. Q.	0.526	0.495	0.485	0.469	0.454	0.467

* Die Pseudomorphosen, p. 165.

	VII.	VIII.	IX.	X.	XI.	XII.
Silica	57.20	45.57	58.48	58.19	55.20	43.9
Alumina....	....	3.00	} 0.88	{ 0.18	....	1.9
Protoxide of manganese	....	....			....	....
Protoxide of iron	4.37	19.73	9.22	7.93	11.82	52.2
Lime	13.39	4.40	0.04	....	....	0.5
Magnesia	22.85	23.40	31.38	30.79	30.73	1.1
Water	2.43	2.00	....	1.86	2.25	....
	100.24	98.10	100.00	98.95	100.00	99.6
O. Q.	0.469	0.685	0.473	0.454	0.513	0.514

Analyzed by

I. Diopside, from Reichenstein Richter.*

Completely converted into asbestos at some parts.

II. Mineral resembling asbestos, and originating } Richter.*
from I

III. Asbestos in long fibres, from Schwarzenstein, } Meitzendorff.†
in the Zillerthal

This mineral has precisely the composition of the pure augite without alumina. It is, therefore, possible that augite may be converted into asbestos without chemical alteration.

IV. Asbestos from Tarantaise in Savoy Bonsdorff.‡

This mineral contains 0.66 hydrofluoric acid, and is analogous in composition to the tremolite of Gullsjö, also analyzed by this chemist.

V. Kymatine (Breithaupt) from Kuhns- } Rammelsberg. §
dorf in Saxon Voigtland

This mineral is asbestos, which, like the preceding, has the composition of tremolite, the purest variety of hornblende.

VI. White asbestos, in long fibres, from } Scheerer. ||
the Tyrol

VII. Mountain cork from the Zillerthal Scheerer. ||

VIII. Asbestos from Pitkaranda, on the } Hess. ¶
Ladoga lake

According to Blum** this mineral is augite that has been converted into asbestiform hornblende.

* Poggend. Annal. lxxxiv, 384, and 383.
 † Ibid. lii, 626.
 ‡ Schweigger's Journ. xxxv, 140
 § Suppl. p. 73.
 || Poggend. Annal. lxxxiv, 383.
 ¶ Kastner's Archiv. v, 321.
 ** Loc. cit. p. 164.

	Analysed by
IX. Asbestos from Koruk in Greenland	Lappe.*
X. Asbestos from dykes in serpentine at the source of the Tschussowaja in the Ural	Heintze.†
XI. Mountain wood from Staaten Island	Beck.‡
XII. Asbestiform augite	.... Gruner.§

A comparison of II and I shows that the conversion of diopside into an asbestiform mineral is intimately connected with a partial substitution of magnesia for lime. It is, therefore, the same kind of alteration that takes place in the conversion of augite into hornblende, except that the displacement of the lime by magnesia is further advanced in this case. The increase of protoxide of iron may be owing to the presence of carbonate of iron in the water by which the decomposition was effected; and thus a portion of silicate of lime would be converted into protosilicate of iron.|| By these two processes, bicarbonate of lime is removed by water. The reduction of the oxygen quotient, although small, shows that there is, proportionately, more lime removed, than magnesia and protoxide of iron introduced. The origin of the asbestos, represented by III and IX, is not known; but it is easy to perceive that they may have been formed from augite or from hornblende. It appears tolerably uniformly the case, that the amount of lime diminishes as that of magnesia increases; where the latter reaches its maximum, the former is reduced to a minimum. The process of alteration already pointed out to have taken place in the conversion of augite or hornblende into asbestos may, therefore, be supposed to take place in all instances. As the amount of protoxide of iron in VIII, IX, X and XI is increased, it follows, that in the formation of this asbestos the carbonate of iron may have taken a greater share in the decomposition than in the case of asbestos, containing but a small amount of iron. The augite XII shows that even the nearly pure protoxide of iron augite may acquire asbestiform structure. The close correspondence between the oxygen quotients of these minerals, with the exception of VIII,¶ is remarkable; for, although there is no

* Poggend. Annal. xxxv, 486.

† Ibid, lviii, 168.

‡ Dana's Mineralogy, p. 692.

§ Comptes rendus, xxiv, 794.

|| See ante, p. 77, No. 50.

¶ With regard to the analysis of this asbestos, it must be observed that a method was adopted which could not furnish accurate results, as is evident from the considerable deficiency. A repetition of this analysis is desirable.

doubt that all asbestos is merely a product of the alteration of other minerals, the substitution of protoxide of iron, lime, and magnesia takes place in proportions, which are more nearly equivalent than is the case in the alteration of any other mineral. For this reason, the alteration of augite may be supposed to take place without alteration of the mass; and this is in accordance with the fact that the pseudomorphs are not porous. It does not appear that the presence of lime in these minerals, amounting to 17·76 per cent., or its total absence, exercise any influence upon the peculiar structure of these minerals. The varieties of asbestos that are free from lime, IX, X and XI, approximate, in other respects, to steatite in composition. It is, therefore, probable that, in the conversion of augite into steatite, the several varieties of asbestos, from those containing the largest amount of lime, to those without lime, are successively formed in the first instance.

Since the asbestos represented by IV and V correspond so closely with hornblende in composition, they may have originated from this mineral. However the conversion of augite into hornblende, as well as the conversion of hornblende into asbestos, involves a decrease in the amount of lime, and an increase in the amount of magnesia; so that the conversion of augite into hornblende may have preceded the conversion of hornblende into asbestos, the original mineral in this case having been augite.

Weibye* observed at Krageroe, in Norway, an alteration of hornblende crystals, situated in cavities of gneiss, partly upon diopside crystals, or covered by them. The laminar structure appears upon some of the exterior faces of the crystal, or the crystals are separable into laminæ, which finally appear as silky asbestos fibres.

Specimens of asbestos from Zöblitz and Taberg in Wermland, which I saw in the Berlin collection, were partly intersected with magnetic iron ore, and partly imbedded in it. There can be no doubt that the augite was highly ferruginous, in the alteration of which magnetic oxide of iron was separated. In this collection I also found mica, intersected by asbestos, from Kariäth in Greenland.

Serpentine with the form of augite.—This pseudomorph was first observed by Breithaupt, near Schwarzenburg in Saxony.

* Archiv für Mineral, xxii, 511, and Jahrbuch für Mineral. 1849, p. 777.

Soon after, he found serpentine with the most distinct forms of black augite at Fahlun in Sweden.* Blum also found serpentine as distinct alteration pseudomorphs in the augitic rock at Monzoni in the Tyrol. It is not merely the fine augite crystals—fassaite—which occur mixed with calc-spar in the drusy cavities and fissures, but the whole mass of the rock is converted into serpentine. The crystals have lost their lustre, colour, hardness, and the sharpness of outline; have become dull, dirty, blackish- or greyish-green, and so soft that they may be cut with a knife. At the interior there is seldom any vestige of cleavage; the mass is compact, but not unfrequently there are small cavities in it. The altered augite mass upon which these pseudomorphs are situated is generally compact, traversed by pores, and at some parts very similar to certain kinds of serpentine.

Liebener and Haidinger † describe a large augite crystal that has been converted into serpentine, with small augite crystals attached to it, which likewise appear to be serpentine. G. Rose ‡ mentions pseudomorphous serpentine after augite from Easton in Pennsylvania, the angles of which he was able to measure, and which corresponded with those of augite.

The conversion of augite into serpentine, like the conversion of augite into asbestos, involves the introduction of magnesia and elimination of lime. When the alteration is complete, the lime is entirely removed, but in some kinds of serpentine there is still a small amount of lime. In the lime-magnesia augite the two bases together amount to as much as 43·3 per cent. Assuming that the magnesia substituted for lime is equal to it in amount, there would be as much of the former base as there is in serpentine. In this case, however, the serpentine formed would contain an amount of silica 10 per cent. greater than the most siliceous serpentine. Therefore, the alteration must be attended with elimination of silica, or the magnesia introduced must amount to more than the lime removed. Comparative analyses of augite and the serpentine that has originated from it are, therefore, desirable for the purpose of clearing up this point.

Steatite with the form of augite.—The conversion of augite into steatite, has been observed at many places by Senger, Freiesleben, Eisenlohr, and F. Sandberger.§ The alteration commences at the

* Jahrbuch der Chemie und Physik, lxiii, 282.

† Berichte über die Mittheilungen von Freunden der Naturwissenschaften in Wien, 1850, v. 77.

‡ Poggend. Annal. lxxxii, 523.

§ German edition, ii. 551

surface and according to Blum * the crystals are first covered with a thin, greenish crust, which gradually becomes thicker, yellowish-green, and lastly, yellow when the alteration is complete. At the interior of these crystals there is often found a number of black specks, which consist of undecomposed augite, or the crystals are quite porous. The black colour, lustre, hardness and cleavage of the augite disappear in this alteration.

Blum † describes pseudomorphs, from the northern part of New York, in which not only the augite crystals, chiefly with the form of malacolite, and the crystalline masses, but also the hornblende and mica are altered. They generally occur in drusy cavities of granular limestone. Notwithstanding the softness of the crystals and their alteration, planes of cleavage may be found here and there. It has already been shown that sahlite or malacolite may undergo a decomposition, which would bring them very near to steatite.‡ According to Beck§ the altered augite of Canton, St. Lawrence County, has the composition I.

				I.	II.	III.
Silica	....	....	....	59.75	60.63	85.34
Alumina	....	....	....	...	23.09	1.58
Protoxide of iron	....	....	....	3.40	4.21	1.67
Lime	....	....	....	1.00	1.27	2.66
Magnesia	....	....	....	32.90	0.91	1.70
Water	....	....	...	2.85	9.12	5.47
				99.90	99.23	98.42
O. Q.	....	....	....	0.450		

This result would correspond with many specimens of steatite.

In altered laminar malacolite from Antwerp, New York, the laminar structure still remains, and the directions of the cleavage planes are indicated by fine black lines. Some of these planes of cleavage are colored brown by hydrated peroxide of iron that has been separated. Besides, many specimens of unaltered malacolite present these lines as indications of the cleavage planes.

It has been seen, that a substance, having the composition of steatite, is formed when the alteration of augite extends to the

* Die Pseudomorphosen, p. 137.

† Nachtrag, p. 76.

‡ See ante, p. 310.

§ Silliman's Amer Journ. xlv, 32.

complete displacement of lime by magnesia.* The largest amount of magnesia in augite is 22·57 per cent. If the lime is displaced by means of bicarbonate of magnesia it would yield 80 per cent. steatite. Comparing the specific gravity of augite with that of steatite, it appears that the loss of substance amounts to 20 per cent., provided the volume is not altered. Hence it is intelligible that augite crystals may be completely converted into steatite without loss of form or alteration of volume.†

Cimolite with the form of augite.‡—According to Rammelsberg this pseudomorph has the composition II, which exactly corresponds with Klaproth's § analysis of the cimolite of Argentiera.||

Hydrated silica—opal—with the form of augite.—Augite crystals occurring in the porous scoriaceous lava at Vesuvius, especially in the crater, present alterations which are unequally advanced in different crystals. The crystals are from one to three lines in diameter; sharp in outline; with a fatty lustre; white, yellowish, or reddish-white. At the commencement of the alteration the black colour passes gradually into greenish- or bluish-grey, then yellowish-white, and lastly a whitish crust resembling porcelain is formed. At the interior there is a dark-colored nucleus, the size of which is proportionate to the stage of alteration; and finally, when the alteration is complete, the whole mass appears white. As in many other pseudomorphs, the surface of the crystal is firm and coherent, while the interior has become cellular and porous from loss of constituents.¶

According to Rammelsberg,** these altered augite crystals have the composition III.†† The whole of the bases proper to the original mineral have, therefore, been extracted. Rammelsberg conjectures that in the neighbourhood of the volcano, stronger acids than carbonic acid have exercised a decomposing action upon the augite, and that in this way the alumina was removed. As sulphurous and hydrochloric acid are evolved with large quantities of water vapour from Vesuvius, it may be supposed that such an

* See ante, p. 310.

† See Chapter xli.

‡ See ante, p. 125.

§ Beitrage i, 291.

|| In the Berlin collection of minerals, I saw some fine specimens of decomposed augite crystals, some of them very large ones from Bilin. A few of them have cavities containing laminae of mica, which also occur upon the faces of the pseudomorph.

¶ Blum—Die Pseudomorphosen, p. 59.

** Poggend. Annal. xlix, 390.

†† See ante, p. 323.

action took place; but the unaltered condition of the surfaces of the crystals cannot in this way be accounted for.

Conversion of lime-protoxide of manganese augite, into braunite and pyrolusite.—Ebelmen* analyzed the following lime-protoxide of manganese augite, both in the normal and altered condition. In the same specimen unmistakable signs of transition from the unaltered to the altered substance may be traced.

Rhodonite from Algiers.

UNALTERED.				ALTERED.			
Silica	....	....	45.49	Water	....	....	13.14
Protoxide of manganese	....		39.46	{	....	....	43.00
					Oxygen	....	....	8.94
Protoxide of iron	....	...	6.42	Peroxide of iron	....	....	6.60
Lime	....	....	4.66		....	....	1.32
Magnesia	....	....	2.60				
				Gelatinous silica	....	....	2.40
				Rose-colored residue identical with the unaltered mineral	....	....	27.20
			98.63				99.60

In this alteration the silica and the magnesia are entirely, and the lime partially, removed; for the 2.40 per cent. gelatinous silica probably originated from a partial decomposition of the mineral remaining unaltered. The protoxides of iron and manganese combined with oxygen, and became hydrated. The total removal of the magnesia, and the mere partial removal of lime do not appear to take place in the alteration of other augite. The cause of the removal of silica is probably to be sought for in the large quantity of protoxide of manganese in silicate of manganese and in the tendency of this substance to become peroxidized. By this oxidation the chemical affinity of protoxide of manganese and silica is annulled, and as there is no such affinity between peroxide of manganese and silica the latter may be the more easily removed.

The 43 per cent. protoxide of manganese in the altered mineral requires for conversion into peroxide 9.64 oxygen, and as 8.94 per cent. oxygen was found, it is evident that the greater portion had been peroxidized. This alteration may, therefore, be

* Comptes rendus, xx.

effected by atmospheric oxygen in the wet way, and it is very probable that the native peroxide of manganese—pyrolusite, etc.,—has originated in this way, from minerals containing protosilicate of manganese; carbonate of manganese is likewise subject to conversion into peroxide as is shown by the carbonate deposited from mineral water.

Probably the peroxide of manganese in drusy cavities of amygdaloid rocks,* may have a similar origin.

Native peroxide of manganese loses by ignition a variable quantity of water. The experiments of Berthier, Rammelsberg, Winckelblech, and Mitscherlich show that there is a hydrated peroxide of manganese, and that there are several compounds of the peroxide with water. In the altered rhodonite, the greater part is in the state of hydrate.

Bustamite from Mexico.

UNALTERED.				ALTERED.				
Silica	44.45	Water	....	....	10.68
Protoxide of manganese			26.96	{	....	....	55.19
Protoxide of iron		1.15		Oxygen	....	....	10.98
Lime	14.43	Peroxide of iron	....	....	1.56
Magnesia	0.64	Carbonate of lime	....	....	14.03
Carbonate of lime		12.27	Silica and quartz	....	....	8.53
				99.90				100.97

The specimen examined was mixed with some carbonate of lime, probably originating from a previous decomposition; for the oxygen of the bases amounts to 0.87 per cent., less than half the oxygen of the silica, showing that a portion of the bases had been removed. During the alteration, water removed not only this carbonate of lime, but also the greater portion of the lime converted into carbonate, as well as the magnesia and silica. The 55.19 per cent. protoxide of manganese would require for conversion into peroxide 12.41 oxygen. The oxygen found, amounts to 1.43 less than this; so that the greater part of the protoxide had been converted into peroxide.

Comparison of the different kinds of silicate of manganese will show that the alteration does not always consist in peroxidation of

* See ante, p. 134.

the protoxides, as in the above-mentioned minerals; but that carbonate of manganese is frequently formed.*

The rhodonite, from Saint Marcel, has undergone another kind of alteration, as is shown by Ebelmen's analyses :—

Rhodonite from Saint Marcel.

UNALTERED.		ALTERED.	
Silica	46.37	Water	1.10
Protoxide of manganese	47.38	{ Oxygen	44.71
Lime....	5.48	{ Oxygen	4.44
			0.90
		Gelatinous silica	8.00
		Pale red residue identical with the unaltered mineral }	41.47
	99.23		100.62

In this alteration the silica is entirely removed, the lime almost entirely, and the gelatinous silica has the same origin as in the case of the decomposed rhodonite; but the protoxide of manganese is converted into braunite, so that it would seem the alteration has not advanced so far as in the case of the rhodonite from Algiers. The decomposed rhodonite from Saint Marcel appears to have the composition of marceline.

Conversion of augite into mica and green earth. Blum† states, in reference to this alteration, that most of the crystals in a specimen of augite called fassaite, from the Fassathal, are dull at the surface, or have only a slight lustre; are rough and drusy, the lateral faces being porous. Here and there laminæ, or six-sided plates of brownish- or leek-green mica have been formed upon the surfaces of the crystal, in a plane with them, and not projecting. The interior of the crystals presents the alteration more distinctly. Here the mass has little coherence, but is porous, and intersected in all directions by laminæ of mica, forming, at some places, a complete mixture, in which mica sometimes preponderates; so that the augite substance is almost entirely displaced. This is especially the case where the crystals are implanted upon a mixture of mica and augite. There is no doubt that the mica has originated from the augite; for it is very improbable that it was

* See ante, p. 133.

† Nachtrag, p. 30.

enclosed by the augite substance in the act of crystallization, particularly on account of the state of the crystals.

The occurrence of green earth, with the form of augite, has already been alluded to.* The following results of analyses by Rammelsberg elucidate this alteration :—†

	I.			II.	III.	IV.
	a.	b.	c.			
Silica	39.18	...	54.42	46.58	56.80	50.83
Alumina	10.31	...	14.21	12.16	15.32	2.16
Protoxide of iron	15.66	...	21.60	} 29.02	12.06	13.50
Peroxide of iron	8.94	32.57‡	...		.....	...
Protoxide of manganese ... ..	...	...	...	...	.....	7.56
Oxide of manganese ... ..	...	...	...	...	3.72	...
Carbonate of lime	15.24	55.52	...	...	4.85	21.73
Magnesia	1.70	4.15	0.77	2.01	5.05	3.42
Alkali... ..	} 8.67	Potash 1.82	5.40	} 10.23	Soda 3.14	0.38
Water and Loss		5.94	3.60		Potash 0.34	0.96
	100.00	100.00	100.00	100.00	101.28	100.56

I. Green earth with the form of augite, from the Fassathal, occurring imbedded in a greenish or yellowish-white earthy mass, which is, very probably, decomposed basalt. The colour varies somewhat; the darker specimens present distinct indications of the laminar fracture of augite, and a greater degree of lustre than the paler-coloured specimens. It was not possible to select such crystals as presented exactly the same exterior appearance.

- I, a. Green earth as a whole.
- I, b. Portion soluble in hydrochloric acid.
- I, c. Portion insoluble in hydrochloric acid, amounting to 72.55 per cent.

If water removed from I a, the soluble portion I b, there would remain a substance having the composition I c, which is very similar to that of potash-mica. If water removed from I a, only the lime, there would remain a substance having the composition II, which likewise approximates to that of potash mica.

These analyses show that alkalies may be introduced into aluminous augite. This is likewise shown by the augite, represented by III, from Ostheim, near Hanau, and analyzed by C. Gmelin,§ as well as by the augite represented by IV, from the lake of Laach, and analyzed by myself.|| There can be no doubt

* See ante, p. 130.
† Poggend. Annal. xlix, 391.
‡ Containing some alumina.
§ Jahrbuch für Mineral 1840, p. 549.

|| The alkalies indicated in this analysis do not originate from an admixture of zeolite substance, as is evident from the fact that they are not extracted by digestion with hydrochloric acid. See ante, p. 305.

that the introduction of alkalies was effected by the reaction of silicate of lime with water containing alkaline carbonates;* for in III there is only a small portion of the lime in the state of carbonate, while in I *a*, the entire amount is in this state, in which it is separated in the alteration. If the alteration were to advance in III until the whole of the lime were eliminated, the amount of alkalies would be increased, and the composition would approximate nearer to that of mica, especially if the soda were, at a more advanced stage of the alteration, displaced by potash.† From a chemical point of view, therefore, no objection can be raised against the possibility of the conversion of augite into mica.

In the augitic porphyry of Pozza, in the Tyrol, green earth occurs with the form of augite, according to Blum.‡ The alteration commences at the surface which becomes covered with a green crust which extends between the more easily separable laminæ, giving rise to a mixture of green earth and augite substance; until, finally, the latter disappears entirely, and only the form of the augite remains. The black colour of the augite is altered into blackish- and mountain-green although not always uniformly.

Blum found that most of these crystals effervesced with acids, and that, in almost all of them, aggregates of carbonate of lime might be recognized. In some instances very thin layers alternated with similar layers of green earth in the direction of the perfect planes of cleavage. More frequently the calc-spar was in small isolated, irregular masses. All the crystals contain small black particles of magnetic iron ore.

When a product of decomposition which, like the carbonate of lime in this instance, is so readily removable by water, appears at the place where the decomposition took place, water cannot have had more than a very limited access. It must, therefore, be conjectured that the augite was merely moistened by water containing some carbonic acid and carbonate of potash, and that the carbonate of lime originating from the decomposition of the silicate of lime was at once deposited between the cleavage planes. The water dropping upon the augite was undoubtedly so scantily supplied that meanwhile the carbonate of lime became so perfectly solidified as to resist solution. This process of alteration, like all others, presupposes very long periods of time. The small

* English edition, i, p. 8, No. 5.

+ See ante, p. 65, No. 38.

‡ Die Pseudomorphosen, p. 207.

black granules of magnetic iron ore are undoubtedly products of the alteration likewise.

Conversion of augite into hornblende and garnet, or into hornblende and magnetic iron ore.—Forchhammer* describes remarkable alterations that augite has undergone in the deposits of iron ore at Arendal in Norway. It has been converted most frequently into hornblende and garnet. One crystal with rounded corners was perfectly unaltered; in another the laminar structure of hornblende was here and there recognizable; a third distinctly presented the form of augite, while the interior consisted of a mixture of perfectly developed laminae of hornblende with granules and well developed crystals of garnet. In some of the crystals, the garnet crystals were so situated in the altered augite, that their faces coincided with those of the augite crystal, and the whole appeared like a porphyritic mass with imbedded garnet. Where the alteration was furthest advanced, the interstices between the garnet and hornblende were filled with calc-spar.

Forchhammer also describes instances of the conversion of augite into hornblende and magnetic iron ore. Unaltered augite and these products of its alteration occur in the same specimen. In some instances epidote was also a product of the alteration.

From the occurrence of magnetic iron ore in Norway, it may be inferred that these alterations are not by any means rare. Thus, at Arendal the magnetic iron ore branches out into the adjoining rocks consisting of garnet, hornblende, augite, etc., which are full of scattered granules of magnetic iron ore. Near Krageroe magnetic iron ore occurs frequently associated with hornblende and calc-spar.†

The conversion of augite into magnetic iron ore will be treated of in Chapter xliii.

Decomposition of augite.—Incrustations of hydrated peroxide of iron, or of ferruginous clay, corroded and incrustated patches and holes are often met with upon augite crystals which are in other respects unaltered. At these parts there are frequently small laminae of mica, as I have observed in many augite crystals, particularly those which have been immersed for ages in the lake

* Amtlicher Breicht über die 24^{en} Versammlung deutscher Naturforscher und Aerzte in Kiel, p. 281.—Compare also Scheerer—Jahrbuch für Mineralogie, 1843, p. 631, et seq.

† Weibye—Archiv. für Mineral. xxii, 465 et seq.—Forchhammer's opinion that this alteration has been effected by a prolonged action of heat, insufficient for uniform fusion of the mass has, I think, been sufficiently refuted. See German edition, ii, 569.

of Laach. There can be no doubt that the formation of these crystals, their decomposition at some parts and the separation of a ferruginous clay were anterior to the formation of the mica laminæ. L. v. Buch* has described augite crystals from Monzoni that were rough, dull, full of holes, and corroded ; some parts presenting a certain degree of lustre owing to the presence of mica laminæ.

Differences in the colour of a crystal, as in diopside, which is green, greenish-white, and colorless, likewise indicate that alteration has commenced.

The above-mentioned alterations of augite have been effected by means of oxygen converting protosilicate of iron into persilicate, and of carbonic acid converting the silicate of lime into carbonate.

DIALLAGES, BRONZITES, AND HYPERSTHENE.

Occurrence.—Diallage is a mineral which has considerable geological importance, for it occurs as an essential constituent of gabbro, a rock associated with labrador at many places and frequently extending many miles or forming isolated mountains several thousand feet high.

Bronzite occurs in basalt, but not very frequently ; in augitic dolerite, and most abundantly in serpentine. Its occurrence upon dykes in granular limestone at Amity, in New York, is remarkable.

Composition.

	I.	II.	III.	IV.	V.
Silica	50.11	51.34	53.20	53.71	53.74
Lime	18.66	18.28	19.09	17.07	4.73
Magnesia	15.72	15.69	14.91	17.55	25.09
Protoxide of iron	7.55	8.23	8.67	8.08	11.51
Protoxide of manganese ....	....		0.38		0.23
Alumina	6.68	4.39	2.47	2.83	1.34
Water ....	....	2.11	1.77	1.04	3.76
	98.72	100.04	100.49	100.28	100.40
O. Q.	0.628	0.586	0.537	0.546	0.530

* Geognost. Briefe, 1824, p. 120.

	VI.	VII.	VIII.	IX.	X.
Silica	57.19	56.81	55.75	58.0	58.45
Lime	1.30	2.20	4.83	....	0.61
Magnesia	32.67	29.68	25.97	29.66	32.83
Protoxide of iron ...	7.46	8.46	5.72	10.14	1.09
Protoxide of manganese	0.35	0.62	(Cr ² O ³ 1.07)	1.00	...
Alumina	0.70	2.07	4.21	1.33	0.09
Water	0.63	0.22	0.42	....	6.56
	100.30	100.06	97.97	100.13	99.64
O. Q.	0.526	0.533	0.518	0.497	0.448

Analyzed by

I. Augite from the Rhone *

Kudernatsch

II. Diallage with metallic lustre from Grossart in the Province of Salzburg.

This analysis corresponds closely with one by Kobell †

III. A similar mineral from Gabbro in Tuscany.

IV. A similar mineral from Baste.

V. Crystallized diallage from the same locality.

This mineral has the usual crystal form of augite occurring in basalt and is the only specimen of crystallized diallage that has yet been found.

VI. Bronzite from masses of olivine in the basalt of Stempel near Marburg.

VII. Bronzite from a mineral resembling olivine at the Seefeld Alps in the Ultenthal, Tyrol.

These six minerals were analyzed by Köhler. ‡

VIII. Granules from a globular mass
of olivine from the Dreiser-
weiher, in the Eifel } Kjerulf

These granules were transparent, of a green colour, and sometimes blue by reflected light. As this mineral has a composition similar to the bronzite represented by IV and V occurring in olivine, it would appear to be bronzite also.

* See ante, p. 312, No. xxvi.

† Journ. für prakt. Chemie. xxx, 472.

‡ Poggend. Annal. xiii, 101.

IX. Bronzite from Ujardersval in Greenland Analyzed by
v. Köhler

X. Magnesian diallage from Presnitz in Bohemia T. L. Schreyer *

This mineral has a perfect cleavage in one direction and a less perfect, but distinct cleavage in a plane at right angles to the other.

The analyses of some varieties of diallage by Legendre † present a general correspondence with those quoted.

The amorphous diallage represented by the analyses I to IV inclusive, present a tolerable correspondence in point of composition with the aluminous augites. For example with I: except that the amount of alumina is somewhat less than in augite, and for that reason the oxygen quotients of these minerals are less than those of most aluminous augite.

While the proportion of lime and magnesia in the uncrystallized diallage is nearly the same as in the aluminous augites, the amount of lime in the crystallized diallage is much smaller, and that of magnesia very much larger.

The oxygen quotients of bronzite correspond so closely with those of diallage that no essential difference can be recognized between them in this respect. But in bronzite the amount of lime is very small, while that of magnesia is considerable. This constitutes an essential difference between bronzite and the uncrystallized diallage; but this difference does not exist between bronzite and crystallized diallage.

A comparison of the analyses of diallage and bronzite with those of asbestos ‡ shows similarities, especially between the asbestos represented by IX and X, and the bronzite represented by VI and VII. In both minerals the lime is either much reduced in amount or entirely wanting, while the magnesia amounts to nearly as much as in steatite. However, the bronzite does not, according to Köhler's description, present any of the external characteristics of steatite.

When it is remembered that in most of the alterations of augite, lime is eliminated and magnesia substituted for it, there is some possibility that diallage and bronzite may, likewise, have

* Poggend. Annal., lxxxiv, 369.

† Ann. des Mines. Sér. 3, xiii, 147.

‡ See ante, p. 320.

originated from augite. The fact that crystallized diallage has the form of augite, the presence of water as a constituent, the differences of colour in the same crystal, and the unequal lustre of the different cleavage faces would appear to indicate that it has been formed by alteration of augite.

The diallage from the gabbro of Baste and particularly that from La Presse in Veltlin, is blended with hornblende, where it borders upon labrador. The former instance is described by Köhler; the minerals are attached only at the edges. In the gabbro of Veltlin, the hornblende generally preponderates over the diallage. Where the constituents of the gabbro are in small granules, hornblende and labrador only occur; and it is only the larger granules of hornblende that have a nucleus of diallage.

G. Rose is of opinion that these blended minerals represent the first stage of the conversion of augite into hornblende. Comparing the composition of aluminous augite and hornblende, as well as that of diallage, it may easily be understood that such augite might be converted into hornblende and diallage, and that the hornblende might become blended with the uncrystallized diallage. The above-mentioned essential difference between the composition of the crystallized and uncrystallized diallage may be regarded as indicating that the substance originating from augite by the substitution of magnesia for lime is capable of crystallizing only when this alteration has gone on to a considerable extent. If, on the other hand, diallage is formed by direct combination of its constituents, and if the crystalline variety has originated from the uncrystalline, a far advanced substitution of magnesia for lime would likewise have taken place. It is to be regretted that there is only one analysis of crystallized diallage, and additional analyses alone can determine whether it is only the diallage with a small amount of lime that is capable of crystallizing.

Conversion of diallage and bronzite into serpentine.—The close relation of gabbro and serpentine has already been pointed out by v. Buch.* The Fichtelgebirge, Erzgebirge, and the Ural furnish instances of this.† At several places bronzite is associated with magnetic iron ore and quartz; according to G. Rose‡ diallage that has been converted into serpentine, occurs near Auschkul in the Ural. The cleavage in the direction of the principal faces, of the tabular crystals was well preserved, and Hermann's analysis

* Geognostische Beobachtungen, i, 45.

† German edition, ii, 607 et seq.

‡ Poggend. Annal. lxxxii, 525.

of this substance, considered by G. Rose* to be coarse-grained diallage, shows that it had the composition of serpentine. This alteration he supposed to have been effected by a total displacement of lime by magnesia and elimination of about 10 per cent. silica. In this respect the association of quartz with diallage, observed at other places is significant. These facts and the investigations made by Delesse† prove the conversion of diallage into serpentine, which had already become probable from the previously known conversion of augite into serpentine.‡

Decomposition of diallage.—In the grauwacke at Ehrenbreitstein, there is a dyke at least forty feet thick, filled with a very decomposed mass that might be taken for gabbro. The rock effervesces with acids, particularly at the surfaces where it is entirely decomposed; less at the interior where the decomposition is less advanced, and generally only where it is intersected by parallel veins of yellowish-white, ochre-yellow or ochre-brown calc-spar. It contains a large quantity of granules of magnetic iron ore, and less frequently laminæ of mica. Here and there it is traversed almost through and through with iron ochre. In small drusy cavities crystallized quartz and iron-spar occur.

In this instance, carbonate of lime appears as the product of the alteration of diallage, and in considerable quantity, especially when it is taken into account that there are two springs which rise from this dyke, and that the carbonate of lime is continually removed by their water.

HYPERSTHENE.

Occurrence.—This mineral is an essential constituent of hypersthene rock or hyperite, occurring at Paul's Island, the coasts of Labrador, and several other places; it also occurs in greenstone and granular limestone. In hyperite it appears to be always mixed with labrador.

* Journ. für prakt. Chemie. lxvi, 226.

+ Bulletin de la Soc. Géolog. de France. Sér. 2, vi, 547.

‡ See ante, p. 321.

	I.	II.	III.	IV.	V.
Silica	54.25	51.35	58.27	46.11	51.36
Lime	1.50	1.84	...	5.38	3.09
Magnesia	14.00	11.09	18.96	25.87	21.31
Peroxide of iron	24.50	FeO 33.92	14.42	12.70	21.27
Protoxide of manganese	trace	....	6.34	5.29	1.32
Alumina	2.25	....	2.00	4.07	0.37
Water	1.00	0.50	....	0.48	
	97.50	98.70	99.99	99.90	98.72
O. Q.	0.508	0.465	0.429	0.735	0.545

I. Hypersthene, from the coast of Labrador. Klaproth.*

II. Hypersthene, from Skye.

III. A variety of hypersthene, in a quartzose specimen, from Baffin's Bay.

IV. Hypersthene, from Paul's Island.

These three minerals were analyzed by Muir.†

V. Hypersthene, from the same locality. Damour.‡

The great differences, especially between II, III, and IV, would, if the analyses are correct, admit of the inference that the specimens selected for analysis were more or less impure. The analysis V appears to be most trustworthy, the oxygen quotient agrees with those of bronzite and diallage. The structure and the four planes of cleavage in the hypersthene and bronzite of Marburg likewise correspond perfectly; so that, as Köhler remarks, there is neither chemical nor mineralogical reason for regarding these minerals as distinct. It is certain, at least, that the same alteration and decomposition that take place in bronzite and diallage may also be supposed to take place in hypersthene, and probably do take place.

The granules of hypersthene from the hypersthene rock of Penig, in Saxony, are blended with hornblende at the edges, where they are in contact with labrador, as well as at the sides of small cracks, by which they are frequently intersected. It is not improbable that this hypersthene has originated from hornblende, or perhaps, both have originated from augite.§

Decomposition of hypersthene.—Beyond Boppard, on the Rhine,

* Beiträge.

† Thomson.—*Outlines of Mineralogy*, i, 202.

‡ *Annal. des Mines*. Sér. 4, v, 157.

§ See ante p 315.

a rock, which is either hyperite or gabbro, occurs in clay state. It is irregularly fissured in many places, and traversed in all directions by numerous veins of calc-spar and quartz.*

Several fragments of the crystalline rock were immersed in acid: where the rock was unaltered, although covered here and there with small ochre-brown patches, it did not effervesce; but at the altered parts it effervesced, although sometimes only at a few places. In a specimen intersected by quartz layers, the most copious effervescence took place at the line of junction with the quartz. Effervescence takes place also at some places in the quartz. The rock adjoining these quartz layers effervesces copiously, and it is here that the decomposition has been most considerable. There is a smaller dyke, consisting of quartz, with copper and iron pyrites, traversing the larger dyke of crystalline rock; and oxide of manganese, with calc-spar, occurs in drusy cavities, altogether forming a conglomerate, in which there are all the products of the decomposition of these minerals.

Several pieces of clay slate from the neighbourhood of the crystalline rock effervesce here and there with acids; and there can be no doubt that the carbonate of lime has been transferred, by means of water, from the crystalline rock into the clay slate.

Nor can there be any question that the calc-spar and quartz veins, as well as the oxide of manganese, are merely products of the decomposition of hypersthene or diallage.

Some specimens of hyperite from the Ruhr, which was described by v. Dechen,† when examined with acid, did not effervesce when fresh, but effervesced copiously when altered. A white incrustation appeared to consist entirely of carbonate of lime, for it was dissolved by acids. A clay-slate rock overlying this hyperite did not effervesce more than very slightly at a few places.

Near Schweppenhausen, on the Hundsrück, isolated masses of rock project from the summit of the left declivity, which also appears to be hyperite. Between the attached masses there is hydrated peroxide of iron, and the fissures are filled with calc-spar. The hydrated peroxide extends into the interior, where the decomposition is most advanced; and this is likewise the case with the calc-spar.

G. Rose‡ mentions hyperite occurring at the Ural river, near Orsk, which contains some admixture of carbonate of lime. This

* German, edition, ii, 614, et seq.

† Archiv. für Mineralogie, xix, 488.

‡ Reise, ii, 191.

rock overlies a bed of jasper, four or five feet thick, which overlies clay slate. Probably in the alteration of hyperite, silica is separated, which has converted the underlying stratum into jasper.

The alterations of augite may be referred to the following heads :—

1. Elimination of lime, and substitution of magnesia.

This takes place in the conversion of augite into uralite and asbestos. By means of a similar substitution diallage, bronzite, and hypersthene may originate from augite. But I do not mean to imply that these minerals are merely altered augite. In the case of asbestos and bronzite, the substitution may extend to the entire removal of lime. When this earth and the other bases are removed entirely, or almost entirely, steatite would be formed. The conversion into serpentine takes place in a similar manner, except that a larger amount of magnesia is introduced.

2. Elimination of all bases capable of combining with carbonic acid.

This takes place in the conversion of augite into cimolite. When other acids than carbonic acid act upon the mineral it is converted into hydrated silica.

3. The decomposition of the lime-protioxide of manganese augite, into braunite and pyrolusite, shows that the silica may be eliminated simultaneously with the lime and magnesia.

4. Augite may also be converted, by partial elimination of lime, into hornblende and garnet, or into hornblende and magnetic iron ore; and this alteration would appear to be effected by means of carbonic acid and oxygen.

5. The lime in augite may likewise be displaced by alkalies, and converted into carbonate; as is shown by the green-earth with the form of augite. Hence there is a possibility of the conversion of augite into mica.

CHAPTER XXXVI.

HORNBLENDE.

THIS mineral, like augite, is of considerable importance, for the several varieties of it are either essential or accidental constituents of a great number of the more frequent rocks. Hornblende consists, like augite, of silicates of lime, magnesia, protoxides and sesquioxides of iron and manganese. In the common hornblende there is also alumina. Hornblende contains fluorine, and in this particular differs from augite.

The ferruginous hornblende is partially decomposed by hydrochloric acid, but the other varieties are not much acted upon. Even sulphuric acid effects only a slight decomposition. Ignition or fusion, does not, according to v. Kobell, bring about any change in its behaviour in this respect. A specimen of hornblende analyzed by Karsten* was perfectly decomposed by prolonged digestion with concentrated hydrochloric and sulphuric acids.

Occurrence.—It was formerly supposed that hornblende and augite very rarely occur together in rocks. However, Naumann † remarks that the association of augite and hornblende in the same basalt is by no means rare. Whenever hornblende is accompanied by augite, the latter is, according to Breithaupt, of anterior formation.‡ A great part of the greenstone in the Ural also contains augite crystals imbedded in hornblende.§

The most frequent varieties of hornblende—grammatite, actinote; common and basaltic hornblende—occur in granular limestone and dolomite,|| especially grammatite. In a limestone quarry at Pargas, in Finland, hornblende has been found most frequently and best crystallized; it is deposited in reinform masses parallel to the stratification of the limestone.¶ The pargasite occurs imbedded in limestone, generally as small unequally developed crystals grouped in veins resembling a string of beads, and parallel to the stratification of the limestone. The largest of these

* Jahrbuch, 1845, p. 651.

† Lehrbuch der Geognosie, i, 651.

‡ G. Rose, Poggend. Annal. xxii, 336.

§ Ibid. p. 329.

|| Hornblende occurs very abundantly and well developed in the limestone of the United States. The crystals are sometimes ten inches long.—Jahrbuch für Mineral. &c. 1849, p. 821.

¶ Nordenskiöld.—Schweigger's Journ. xxxi, 405.

crystals that have been found, were quite detached in a cavity of the rock. Although the crystals are grouped in a reinform manner, each one is surrounded by limestone.

The above-mentioned varieties of hornblende occur also upon metalliferous deposits, together with magnetic iron ore, specular iron, copper pyrites, iron pyrites, galena, etc. Actinote also appears sometimes intimately combined with these ores, and acquires metallic lustre. In a bed of limestone near Grünstadel, in Saxony, there are veins and small dykes of actinote with chlorite (serpentine?) blende, copper pyrites, malachite, etc.* Foreign minerals, such as blue carbonate of copper, are sometimes associated with grammatite and communicate to it accidental colour. These varieties of hornblende and antophyllite, together with augite, mica, chlorite, talc, garnet, epidote, etc., constitute layers in crystalline schistose rocks.

The common hornblende is the most important variety in a geological point of view, since it constitutes the mass of the granular hornblende rock, is an essential constituent of syenite and diorite, and is an accidental constituent of many massive and schistose rocks, particularly granite, hyperite, gabbro, some porphyries, gneiss, micaceous and chloritic schists.

Basaltic hornblende occurs less frequently. Sometimes it occurs in basalt, trachyte, and related rocks, without however, being an essential constituent.

Grammatite and actinote are not essential constituents of any rock. The former occurs mostly in subordinate beds, rarely upon dykes; the latter is here and there an accidental constituent of some crystalline rocks, such as gabbro, serpentine, etc. Actinote, more especially, constitutes subordinate layers either alone or together with hornblende, mica, chlorite, garnet, etc., in gneiss, micaceous-, chloritic-, talcose-, and hornblende-schist. It occurs but rarely upon dykes.

Byssolite occurs upon dyke fissures, and in the drusy cavities of crystalline rocks, especially with rock crystal, adular, thalite, in several parts of the Alps.†

Antophyllite does not occur very frequently. It is sometimes found in micaceous schist; also in granite, diorite, gabbro, serpentine; and basalt.

The conversion of augite into hornblende and magnetic iron ore, in deposits of iron ore at Arendal, has already been treated

* Freiesleben.—Geognost. Arbeiten, vi, 35.

† Hausmann.—Handbuch der Mineral. Ed. 2, p. 208.

of.* In the Solberg mine variously shaped veins of magnetic iron ore intersect the rock, consisting of hornblende. In the Alvelands mine and the Buöe mine it is accompanied by very considerable masses of hornblende.†

At several places near the town of Hekeljord, in Norway, the gneiss has a stratified appearance, owing to the presence of layers of hornblende. These layers are sometimes nearly as thin as paper, sometimes several inches thick. Whether the hornblende laminae are horizontal or perpendicular, the origin of the gneiss in which they are imbedded would be the same;‡ and it is, moreover, impossible to suppose that such thin layers of hornblende can have been formed by fusion.

In metamorphic rocks, at Krageroe, there are unequal-sized cavities, the walls of which are covered with hornblende crystals. They appear stalactitic, with an incrustation consisting of an aggregate of crystallized albite, or of small, pointed crystals of albite. In some of these stalactitic masses the hornblende has entirely disappeared, leaving a cavity sometimes filled with albite. Weibye§ considers that this albite has been deposited from water; and there can be no doubt that the same water has removed the hornblende crystals. Volger|| describes a very fine-grained felspathic rock, penetrated by bunches of actinote, which have been decomposed at the surfaces, where the rock has been exposed to the action of the atmosphere, leaving furrows or grooves, in which lichens have attached themselves.

In the Berlin collection of minerals I saw a garnet crystal, of which scarcely anything remains but the outer portion. At the interior is a druse of black hornblende, which, however, only partially fills the space.

Asbestos, which is a product of the alteration of augite and hornblende,¶ occurs partly upon dykes and veins, partly upon layers in serpentine, gabbro, hyperite, and some other crystalline rocks. It constitutes dykes, or veins, especially in serpentine, which frequently contains large quantities of it, either alone, or associated with quartz, cat's-eye, axinite, thalite, actinote, and sometimes by ores. It occurs with hornblende, chlorite, talc, calc-spar, and bitter-spar, etc.; in beds in gneiss, micaceous,

* See ante, p. 330.

† Scheerer.—Jahrbuch für Mineral. 1843. pp. 654, 660.

‡ Ibid. p. 667.

§ Jahrbuch für Mineral. 1849, p. 776.

|| Ibid. 1854, p. 257 et seq.

¶ See ante, p. 318.

chloritic, and hornblende-schists ; and sometimes in beds of magnetic iron ore, specular iron, copper pyrites, iron pyrites, and other ores.

Formation.—The occurrence of hornblende in lava appears to be indicative of its formation by fusion. However, in the lava at Vesuvius it occurs only at the sides of drusy cavities as acicular crystals ; while the crystals actually imbedded in the lava are only augite and leucite.* In the Berlin collection of minerals there is a specimen of this kind of lava, where the hornblende crystals extend, like threads, from one side of the drusy cavities to the other. A similar phenomenon is presented by sulphur, gradually solidified ; the cavities often contain sulphur crystals, extending from side to side. If the hornblende could have crystallized as readily as sulphur during the solidification of the lava ; and if the lava consisted solely of hornblende substance, the formation of these hornblende crystals, in drusy cavities, might be regarded as similar to that of the sulphur crystals. But this was not the case ; and, therefore, the crystallization must have been subsequent to the solidification of the lava, and its conversion into hornblende. This alteration, however, could only have taken place in the wet way. The lava analyzed by Dufrenoy† presents such a composition, that it may be supposed that augite, leucite, and magnetic iron ore might be formed during crystallization. The two former substances actually occur in the lava, but hornblende does not ; although it is reasonable to suppose that it would have been formed in the drusy cavities, if it could have been separated from the melted mass. Everything, therefore, tends to show, that the hornblende crystals, in the drusy cavities of lava, have been formed subsequently, from the augitic masses it contains.

Hornblende appears to be rare in the lava at Vesuvius. At least, Monticelli and Covelli,‡ who made such a careful examination of the lava and other volcanic products of the eruptions in 1821, 1822, and 1823, do not mention hornblende as a constituent of it. In the lava at Etna, hornblende is more frequent ; but this is the case only in the older lava. Fine crystals of it may be collected from decomposed rocks at the margin of the crater.§ This occurrence in old lava and in decomposed rocks, is further evidence of subsequent formation in the wet way.

* G. Rose.—Reise nach dem Ural, ii, 365.—v. Buch.—Poggend. Annal. x, 16.

† Annal. des Mines, xiii, 565.

‡ Der Vesuv. &c.

§ v. Buch.—Loc. cit. p. 13.—He remarks that no mention is made of augite in these lavas, and that it is not to be found in specimens.

Hornblende, as uncrystallized masses, occurs in the volcanic products of the lake of Laach and its neighbourhood: as, for instance, in the masses ejected from the volcanoes, together with magnetic iron ore, ryakolite, titanite; in lava, ejected masses of hornblende-schist and syenite; also as acicular crystals, and larger well-developed crystals.

Taking all these facts into consideration, there is, probably, not any single ground for supposing that hornblende is formed by fusion.

To the remarks already made,* as to the conversion of hornblende into augite by fusion and slow cooling, may be added the fact, pointed out by Hausmann,† that it yet remains to determine whether there is any decomposition of the mass, or whether a substance having the composition of hornblende is capable, under certain conditions, of assuming the form of augite.

Composition.—The analyses are arranged according to the bases preponderating in the minerals; together with the oxygen quotient.

A HORNBLENDE WITHOUT ALUMINA.

Lime-magnesia hornblende.

		Analyzed by	O. Q.
I. Colourless grammatite, from Gullsjö	....	Bonsdorff‡	0·445
II. Greenish-white grammatite	....	Hisinger§	0·451
III. Pale yellow grammatite	....	Bonsdorff§	0·435
IV. Glassy actinote, from Taberg	....	Bonsdorff§	0·425
V. Grammatite, from St. Gotthardt	....	Damour||	0·450
VI. The same mineral	....	Richter¶	0·439

Magnesia-protioxide of iron hornblende.

VII. Antophyllite, from Kongsberg	....	Vopelius**	0·443
VIII. „ from Perth, in Upper Canada		Thomson††	0·479
IX. The same mineral	....	Hunt‡‡	0·504

* See ante, p. 307.

† Loc. cit. p. 506.

‡ Schweigger's Journ. xxxv, 136.

§ Ibid. xxiii, 257.

|| Journ. für prakt. Chemie. xxxviii, 129.

¶ Poggend. Annal. lxxxiv, 353.

** Ibid. xxiii, 355.

†† Records of General Science, 1836, p. 332.

‡‡ Phil. Mag. Ser. 1, iv, 322.

Lime-magnesia-protioxide of iron hornblende.

			Analized by O.Q.
X. Asbestiform actinote, from Taberg	Murray*	0·421

Soda-protioxide of iron hornblende.

XI. Arfvedsonite	v. Kobell†	0·466
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This hornblende contains 8 per cent. soda, with traces of potash.

The ægyrine in the syenite, at Brevig, appears to be a variety of arfvedsonite, and contains 7·79 per cent. soda, and 2·96 per cent. potash.† Alkalies have also been found in other varieties of hornblende; potash in the Arendal hornblende;§ in the basaltic hornblende of Bilin 1·89 per cent. potash, and 0·96 per cent. soda;|| in the hornblende of the syenite at Servance, 2·95 per cent. potash, with some soda;¶ and in the hornblende of Perth, in Canada, 0·25 per cent. potash, and 0·8 per cent. soda.** I am unable to offer any opinion as to whether the alkalies in these minerals are essential constituents, or whether they belong to intermixed felspathic substance.

With the exception of the minerals represented by VII and IX, which are either altered or impure hornblende, the oxygen quotients agree so closely, that 0·444 may be taken as the normal value. The analyses that have been made of hornblende without alumina, do not present any such differences as in the case of the augites,†† where there had been a partial elimination of bases. Hence it follows that hornblende is less liable to decomposition than augite; and this would also appear from the smaller amount of water in hornblende, amounting, according to Bonsdorff, to only 0·1 or 0·5 per cent. At a white heat the loss amounts to 1, or 2·29 per cent.; but this is, in fact, owing to separation of fluoride of silicium. So large an amount of water as 5 per cent., found in many specimens of sahlite,‡‡ is not met with in hornblende; the antophyllite, from Perth, alone contains 3·6 per cent. There can be no doubt that the larger amount of

* Rammelsberg Suppl. 2, p. 60.

† Journ. für prakt. Chemie. xiii. 3. The 2 per cent. alumina was included among the bases.

‡ Plantamour.—Journ. für prakt. Chemie. xxiv, 300.

§ Pfaff.—Schweigger's Journ. xviii, 73.

|| Struve.—Poggend. Annal. vii, 350.

¶ Delesse.—Extrait des Mémoires de la Soc. d'Emulation du Doubs.

** Hunt.—Phil. Mag. Ser. 1, iv, 322.

†† See ante, p. 314.

‡‡ See ante, p. 309.

lime, in augite, renders this mineral more liable to decomposition than hornblende.

ALUMINOUS HORNBLENDE.

In these minerals the amount of alumina is inversely proportionate to that of silica; and is, generally, greater than in augite. It has not, hitherto, been possible to represent the composition of the aluminous varieties of hornblende in the same manner as that of the hornblende without alumina. Bonadorff* assumed that the alumina replaces a portion of the silica; and that 3 eqts. alumina correspond to 2 eqts. silica.

Rammelsberg† endeavoured to show, that when the alumina is considered as a substitute for silica, the oxygen quotients, calculated from the analyses, approximate to 0·444, that of the hornblende without alumina; but he was unable to obtain exactly this number. Subsequently, he obtained a general formula; but he was, at the same time, compelled to adopt more than seven special formulæ to represent the results of analyses.‡

As native aluminates actually occur,§ it is possible that they may exist in compound silicates; and as the alumina in spinelle is combined with magnesia, and that in pleonaste with magnesia and protoxide of iron, similar compounds may be supposed to exist in aluminous hornblende. The fact, that in these varieties of hornblende, as in most aluminous minerals, alumina and protoxide of iron appear to be mutually replaceable, favours the opinion that they contain a compound analogous to pleonaste.

I have endeavoured to do away with the differences in the oxygen quotients of these hornblendes when the alumina is ranked among the electronegative constituents, by the assumption that in hornblende it exercises the functions partly of a base and partly of an acid.|| Then taking the oxygen quotient of hornblende without alumina, 0·444, as that of the aluminous hornblende also, the amount of basic and acid alumina may be easily calculated. But so long as there is no empirical proof of this, or any other hypothesis respecting the chemical constitution of hornblende, it would be well to abstain from any further attempts to solve this problem by calculation.

* Schweigger's Journ. xxxv, 155.

† Suppl. p. 73.

‡ Suppl. 5, p. 134.

§ See ante, p. 91.

|| German edition, ii, 851.

The analyses of varieties of hornblende cannot be considered as nearly complete. Perhaps the determination of the relative proportions of the oxides of iron would furnish some clue to the true constitution; for it has not been proved that they contain only protoxide of iron; and there is not any ground for this assumption, since other minerals, like tourmaline, for instance, which so closely resembles hornblende in colour, contain both oxides of iron.

Alteration of hornblende.—Although the alteration of hornblende is not so manifold as that of augite, there are several kinds which correspond in the case of both minerals; such as their conversion into asbestos, serpentine, steatite, etc. From the great similarity of hornblende and augite in composition, the alteration of both minerals, under similar conditions, would be the same.

Chlorite with the form of hornblende.—At Greiner, in the Tyrol, Reuss* found hornblende crystals covered with a crust of chlorite. This crust sometimes extends so far inwards as to constitute the principal portion of the crystal, there being only a small nucleus of hornblende at the interior, and sometimes it has entirely disappeared. There has not been any analyses published of the chlorite crust, or the hornblende nucleus; and, therefore, the precise chemical nature of the alteration cannot be pointed out. But it is certain that a portion of the silica and the whole of the lime are eliminated. It is possible that the alteration has been effected by carbonated water decomposing the silicate of lime; and removing the lime, as carbonate, together with some silica.

Serpentine with the form of hornblende.—Breithaupt† describes a mineral presenting a gradual transition from glassy actinote into compact, noble serpentine, sometimes retaining indications of the cleavage. Other specimens present similar alterations. G. Rose‡ describes a piece of serpentine from Easton, Pennsylvania, upon which there are decomposed crystals that have very distinctly the form of hornblende.

The analyses of hornblende and serpentine, associated in this manner, are much to be desired, for the purpose of tracing the process of alteration.

Steatite with the form of hornblende.—Blum§ observed such an alteration in pargasite, from the granular limestone near Pargas.

* Jahrbuch für Mineral. &c. 1840, p. 136.

† Jahrbuch für Chemie. und Physik, lxiii, 282.

‡ Poggend. Annal. lxxxii, 523.

§ Die Pseudomorphosen, p. 18.

It commences at the interior. Several crystals, when broken in two, appeared, with the exception of an external crust, to be wholly converted into steatite. He also observed this alteration in the grammatite of Oxbow, New York.* The masses of steatite generally present the cleavage of hornblende so perfectly, that the cleavage faces are smooth, and have a high lustre. The following analyses throw some light upon this alteration :—

	I.	II.	III.	IV.	V.	VI.
Silica	0.35	62.90	63.25	35.00	34.66	69.79
Magnesia ....	....	28.92	28.92	20.70	25.22	26.50
Alumina ....	....	0.14	0.14	32.33	25.33	} 0.40
Peroxide of iron	0.14†	4.42	4.56	....	....
Lime ....	....	0.04	0.04	10.80	5.09	10.25
Carbonate of lime	0.07	....	0.07	....	....	....
„ „ „ magnesia	0.24	....	0.24	....	....	..
Loss by ignition ....	....	0.86	0.86	1.17	9.09	1.27
	0.80	97.28	98.08‡	100.00	99.39	99.21

The pseudomorph, from Oxbow, represented by I, II, and III, was analyzed by myself. I, portion extracted by hydrochloric acid; II, portion insoluble in hydrochloric acid; III, the mineral as a whole. It is, therefore, steatite, still containing silicate of iron undecomposed. As this grammatite, undoubtedly, contained alumina, it will be seen that this earth is almost wholly eliminated during the alteration.

The analyses IV and V represent decomposed hornblende, from magnesian limestone, at Warwick, Orange County. § L. C. Beck states that the principal difference between the chemical composition of this mineral and that of the several varieties of hornblende, consists in the larger amount of alumina which partly replaced silica. This is apparently the case, but it is difficult to conjecture by what process silica should have been displaced by alumina. The decomposition was unquestionably further advanced in V than in IV. As the amount of magnesia is increased, that of alumina and that of lime are diminished, as is shown by the increased amount of water; so that there has been a displace-

* Nachtrag. p. 15.—Other instances of this kind of alteration are described by Blum.—Nachtrag. 2, p. 12.

† Contained alumina.

‡ The deficiency represents organic substance.

§ Reports of the Assoc. of American Geol. and Naturalists. Boston, 1843 p. 24.

ment of these two earths by magnesia; but much more has been removed than introduced. The silica in IV and V amounts to 6·7 per cent. less than in aluminous hornblende, with the smallest percentage of silica; so that it may be inferred, that silicate of lime was both removed by water and decomposed by magnesian salts* at the same time; and that at a later stage of the alteration a portion of the silicate of alumina was also decomposed by magnesian salts. The occurrence of these pseudomorphs in limestone favours the opinion, that part of the silicate of lime was removed unaltered; for the water would have been deprived of its free carbonic acid while percolating these strata; and would not then exercise a decomposing influence upon the silicate of lime. Lastly, as the magnesia in aluminous hornblende, amounts to as much as 22 per cent., it would appear that only a very small portion of the magnesia in the pseudomorph has been introduced.

The analysis VI represents a mineral from China, which Ebelmen and Salvétat† considered to be a mixture of tremolite with a smaller proportion of steatite. It effervesced copiously with hydrochloric acid, lime and magnesia being dissolved. Unfortunately, the amount of carbonates was not estimated. If silicate of lime still remained in the mineral, it might be regarded as steatite in which the decomposition of the silicate of lime, by magnesian salts, had not been completed. As tremolite is either entirely destitute of alumina, or contains only a very small amount, but a very large amount of magnesia, there would not be any need for the decomposition of much silicate of lime by magnesian salts. The effervescence with acids shows that the silicates are really decomposed to some extent by carbonic acid.‡

Conversion of hornblende into talc.—

	I.	II.	III.	IV.	V.	VI.
Silica	60·60	58·07	60·85	62·85	62·15	61·51
Alumina	0·32	....	1·71	1·44	1·01	0·83
Protoxide of iron	0·50	1·82	0·09	0·20	0·38	0·12
Lime	11·85	12·99	trace.	0·42	0·07	3·70
Magnesia	25·43	24·46	32·08	30·76	33·04	30·93
Water	1·20	....	4·95	4·55	3·21	2·84
	99·90	97·34	99·68	100·22	99·86	99·93

* See ante, p. 66, No. 40.

† Annal. de Chimie et de Physique, xxxi, 257.

‡ Poggend. Annal. lxxxiv, 346.—See chapter xli.

- | | |
|---------------------------------|-------------|
| I. Tremolite, from St. Gotthard | Richter.* |
| II. The same mineral | Damour.† |
| III. Talc, from St. Gotthard | Scheerer. ‡ |

This mineral occurs together with quartz and magnesian calc-spar,§ both of which are often situated between the talc laminæ.

- | | |
|---|-------------|
| IV and V. Radiated laminar talc from the
same locality | } Scheerer. |
|---|-------------|

Externally it appears like concentric shelly tremolite. At places it is likewise blended with quartz and magnesian calc-spar.

- | | |
|---|-----------|
| VI. Asbestiform talc from the same locality | Scheerer. |
|---|-----------|

This mineral presents perfect transitions into those represented by IV, V, and III; all three are associated with the tremolite represented by I.

As these three minerals pass into each other at St. Gotthard, there can be no doubt that the three specimens of talc have originated from tremolite. The silicate of lime is, for the most part, converted into silicate of magnesia; but a portion appears to be decomposed, as is shown by the quartz and calc-spar between the laminæ of talc. As this calc-spar contains carbonate of magnesia it would appear that a portion of silicate of magnesia is decomposed.

As in the conversion of hornblende or augite into steatite or talc, there is but little substance eliminated, and as this is compensated by the introduction of water, it is evident that this alteration may take place without affecting the form or volume of the mineral.||

Jasper with the form of hornblende.—Maier¶ describes crystals and veins of crystals of basaltic hornblende, imbedded in the basalt of the Wolfsberg, near Cernossin in Bohemia, which are sometimes converted into red jasper. Whether all the bases had been removed, leaving the silica, or whether silica had been introduced cannot be ascertained from the description given. Granules of yellow jasper also occur in the basalt, and to judge from some unaltered parts, have originated from augite.

Conversion of hornblende into asbestos.—This alteration has already been treated of.**

Conversion of hornblende into mica.—True pseudomorphs of mica after hornblende have not yet been met with. However, I have

* Poggend. Annal. lxxxiv, p. 353.

† Ann. de Chim. et Phys. xvi, 469.

‡ Poggend. Annal. lxxxiv, 346, 347, and 352.

§ Containing about 3·5 per cent. carbonate of magnesia.

|| Compare chapter xli.

¶ Blum.—Die Pseudomorphosen, p. 58.

** See ante, p. 320.

observed the following phenomena in specimens of hornblende belonging to the Berlin collection of minerals. The green colour of pargasite passes into brownish, the hardness is reduced, pinch-beck-brown laminæ of mica make their appearance; and, in parts, the pargasite appears quite converted into mica. These altered crystals still present their original appearance. At the edges of the altered pargasite the mica is not distinct, as it is of a brownish colour. But the laminæ of mica may be separated with the point of a pen-knife. In the midst of the brown pargasite, mixed with mica laminæ, there is an unaltered nucleus of green pargasite; and here the transition may be distinctly observed. When the mica is separated with a knife, places are found where the mass is gritty and the cleavage disappears. Then follows the brownish pargasite, and, after that, the green unaltered mineral. But even in broken pargasite crystals there are numerous small laminæ of mica.

The common hornblende, occurring as indistinct, long, reed-like crystals, together with small zircon crystals, at Miask, presents distinct indications of conversion into mica. The leek-green hornblende crystals are corroded at the centre, have brown patches of hydrated peroxide of iron, and at the corroded parts the mica laminæ lie mixed in all directions, though sometimes in the direction of the laminar fracture. Where the decomposition is most considerable, the mica laminæ are confused; but where they are isolated, they are parallel with the faces of fracture. In the midst of the hornblende crystals are small patches with laminæ of mica, but they never occur upon unaltered crystal faces. At one place there is a kind of drusy formation. The mica is in a space resembling a three-sided pyramid, surrounded by hornblende, and is apparent only at the base. Unequally decomposed crystals, from Gouverneur, in New York, are covered partly upon the surfaces, and upon the faces of fracture with innumerable laminæ of mica of a gold-yellow colour, and partly very minute. A specimen of hornblende from New Jersey also presents mica laminæ and calc-spar at the transverse fracture.

Basaltic hornblende from the Bodenmais, very fresh, and without ochre-colored streaks, is also covered at many places, on the surfaces of fracture, with thin laminæ of mica arranged in rows. The alteration appears to have just commenced. Another specimen of hornblende, from the same locality, is covered with innumerable laminæ of mica. Many fragments of basaltic hornblende present decomposed patches and hollows in which there

are mica laminæ, and near them ochre-yellow spots. I have found a lamina of mica at the middle of a fracture surface of a large hornblende crystal occurring in hornblende rock. One of the exterior faces of another crystal was covered with numerous laminæ of mica. Some large crystals of hornblende presented films of mica.* The same phenomena are, therefore, presented by hornblende crystals that are observed in augite crystals; in both cases the laminæ of mica upon the altered places can only be of more recent formation.

Probably the mica, which is so intimately blended with the hornblende, from diorite in Corsica, and which is always associated with it, may likewise originate from the alteration of hornblende. This is the more probable from the presence of alkalies in this hornblende, as pointed out by Delesse.

T. H. Fergus† states, that parts of the green-stone rock, near Boston, that have long been exposed to the influence of the weather, are covered with laminæ of mica, but that there is no mica associated with the hornblende at the interior. Several hornblende crystals from the surface, or interior of the rock, presented the usual characters of this mineral before the blow-pipe; but the crystals that had been weathered, acquired, in the outer flame, a lighter colour; and, after cooling, the slightest blow was sufficient to separate them into gold-colored scales, having all the characters of mica.

The potash that must have been introduced into this hornblende, in order to convert it into mica, may have originated from felspar by decomposition, and have been introduced into the hornblende by reaction with the silicate of lime.‡ The colour of this mica would indicate that it is magnesian mica, and that would be consistent with assumed process of alteration, in which the silicate of magnesia in the hornblende is not altered.

Weibye§ describes hornblende crystals, the interior of which are filled partly with calc-spar and partly with mica. In this instance, the substance which must be eliminated, in the alteration of hornblende into mica, is found in the state of carbonate of lime together with the mica.

* German edition, ii, 872.

† Silliman's Journal, 1848, vi, 425.

‡ English edition, i, 8.—Alterations effected by carbonate of potash may be easily accounted for, because every analysis of spring water shows the presence of traces at least of potash salts. Only recently I have found these salts in fresh water form tertiary deposits.

§ Jahrbuch für Mineral, 1849, p. 780.

The frequent transition of hornblende schist into micaceous schist, indicates, particularly, conversion of hornblende into mica.

I add, here, some analyses of substances which appear to have some analogy to those already spoken of.

	I.	II.	III.
Silica	42.50	47.71	46.27
Alumina	22.30	26.43	25.10
Protoxide of iron	18.00	15.51	15.60
Protoxide of manganese	3.60	...	0.89
Lime ....	...	0.48	...
Magnesia	3.10	1.80	3.80
Potash	trace	1.91	2.70
Soda ...	...	0.61	1.20
Loss by ignition	10.00	2.91	6.00
	99.50	97.36	101.56

I. Blackish-brown concretions in the "Fruchtschiefer," a kind of clay slate. } Kersten.*

II. A similar mineral, from the "Fruchtschiefer," of Wechselburg, in Saxony, sent to me by Blum, and analyzed by myself. Owing to the small quantity, I was unable to ascertain the cause of the deficiency of 2.64 per cent.

III. Gigantolite. Trolle-Wachtmeister.†

Blum‡ considers the mineral represented by I to be a pseudomorphous substance, probably originating from hornblende. According to him, many parts of II consist of mica laminæ, and the glittering appearance of the whole mass is owing to the presence of mica laminæ. The composition approximates to that of imperfectly formed mica, except that the amount of potash is small. The close correspondence of this mineral with the gigantolite represented by III, admits of the conjecture that the former may be an intermediate product of the conversion of hornblende into mica, in the same manner that the latter is an intermediate product of the conversion of cordierite into mica.

Decomposition of hornblende.—It has already been remarked § that hornblende crystals frequently present decomposed patches, filled with a brown earthy substance. A similar substance is

* Journ. für prakt. Chemie, xxxi, 108.

† Poggend. Annal. xlv, 558.

‡ Nachtrag, 2, p. 32, et seq.

§ See ante, p. 350.

sometimes found at the interior of the crystals, forming nests and veins, while at the exterior they are quite unaltered.

The dark-colored varieties of hornblende, and particularly the common and columnar hornblende, are, according to Breithaupt, more liable to decomposition than the lighter colored and granular varieties. Hornblende appears to be generally less liable to disintegration than augite; and, inasmuch as the disintegration is a result of the formation of carbonates, this is in accordance with the smaller amount of lime in hornblende. It is for this reason that hornblende rock so rarely effervesces with acids. I have tried a great number of specimens of syenite, both disintegrated and not, at the Felsberg, in the Odenwald, but not one effervesced. Pieces of a fine-grained rock at the Melibokus presented the same character. It was only in a quarry at the Weidenthal, where there is a rock of this kind forming a dyke in coarse-grained diorite, that I found upon the surfaces of union a thin incrustation of carbonate of lime. At the interior, this rock did not effervesce. It is still questionable whether this incrustation of carbonate of lime originates from the rock by decomposition, for loess overlies the rock at a higher point, so that the carbonate of lime may have been deposited by water flowing from that stratum. In the trachyte of the Stenzel, in the Siebengebirge, there are frequently large masses of hornblende crystals, which I have also found do not effervesce.

G. Rose, however, informs me that the granite and syenite, near Meissen and Dresden, effervesce with acids, and Cotta has made the same observation. This granite generally contains hornblende; and when a piece is immersed in acid, effervescence takes place at the borders of the hornblende crystals.

The disintegration of the dark-colored ferruginous hornblende commences with peroxidation of the iron; and it is on this account that corroded patches and holes, filled with hydrated peroxide of iron, are so frequently found at the surface.

When the disintegration is complete, the whole mass is converted into an ochre-brown earthy substance. At an earlier stage of the decomposition a portion of the iron appears to be eliminated as magnetic iron ore. Bonsdorff* states that the powder of a jet-black, brilliant hornblende was attracted by the magnet.

The following analyses throw some light upon the decomposition of hornblende.

* Schweigger's Journ. xxxv, 144

	I.	II.	III.	IV.
Silica	40.27	44.03	45.37	40.32
Alumina	16.36	14.31	14.81	17.49
Peroxide of iron	15.34	25.55	(FeO 8.74)	18.26
Protoxide of manganese ...	...	...	1.50	2.14
Lime	13.80	10.08	14.91	5.37
Magnesia	13.38	2.33	14.33	9.23
Water ...	0.46	3.44	...	8.00
	99.61	99.74	99.66	100.81
O. Q. ...	1.024	1.002	0.808	0.925*

Analyzed by

I. Crystallized hornblende from Wolfsberg, } Göschen.†
near Cernosin, Bohemia.

II. Decomposed hornblende, from the same } Maddrell.‡
locality.

The exterior of this mineral is partly dull and grey-colored, partly lustrous, and reddish-brown. The interior does not present any vestige of cleavage, but an alternation of pale-yellow and brown particles.

III. Unaltered hornblende, from Haavi, on } Suckow.§
Fillefjeld.

IV. Decomposed hornblende, from the same } Suckow.§
locality.

The alterations that have taken place in the minerals represented by I and III, present the common feature of a considerable increase in the amount of iron; so that the alteration must have been effected chiefly by ferruginous water. In the decomposition of the mineral represented by I there is the entirely anomalous result that magnesia has been eliminated in far greater proportion than lime, while in the alteration of the mineral represented by III the reverse happened, as is usual.

Since hydrated peroxide of iron decomposes silicate of lime,|| the partial elimination of lime from the mineral represented by III, and the substitution of peroxide of iron may be accounted for.

* In calculating the oxygen quotients, the alumina was included among the bases, since it is only requisite to institute a comparison between the oxygen quotients of the unaltered and decomposed hornblende.

† Rammelsberg.—Suppl. 2, p. 61.

‡ Poggend. Annal. lxii, 142.

§ Die Verwitterung im Mineralreiche.

|| See ante, p. 77, No. 50.

But the amount of lime in II is little reduced, while that of peroxide of iron is considerably increased; so that it may be supposed the magnesia of the mineral represented by I has been displaced by hydrated peroxide of iron. But this would not be consistent with the small extent to which silicate of magnesia is decomposed by hydrated peroxide of iron.*

The oxygen quotient of II is very little less than that of I, so that the amount of bases cannot have been much reduced; and the substances eliminated must have been nearly compensated for by those introduced. But the oxygen quotient of IV is considerably greater than that of III, so that either the amount of bases introduced was greater than that of bases eliminated, or silica was eliminated also.

	V.	VI.		VII.
Silica	48.91	51.21	Carbonate of manganese	50.52
Protoxide of manganese ...	46.74	42.65	„ iron ...	8.60
Protoxide of iron ...	...	4.34	„ lime ...	37.17
Lime	2.00	2.93	„ magnesia ...	2.44
Magnesia	2.35	trace	Water and loss ...	1.27
	100.00	101.13		100.00
O. Q. ...	0.471	0.427		

V. Rose-colored mineral from Cummington, Massachusetts, called by Hermann manganese-amphibole†

VI. and VII. Probably the same mineral decomposed,

Schlieper found it to consist of carbonates represented by VII to the amount of 9.85 per cent., and a residue which had the composition VI.

The considerable reduction of the oxygen quotient of VI, as compared with that of V, indicates an elimination of bases; but they still remain in the state of carbonates. Therefore, the alteration of the mineral consisted in a partial decomposition by means of carbonated water.

It has been shown that hornblende is subject to nearly the same alterations and decompositions as augite. When the lime is eliminated entirely, and the protoxide of iron partially, chlorite is produced. When at the same time alumina is eliminated, serpen-

* See ante, p. 78, No. 51.

† Die Verwitterung im Mineralreiche.

‡ Journ. für prakt. Chemie. xlvii, 7.

tine is produced, which may, however, retain a small amount of lime. When all other bases besides magnesia are eliminated, steatite or talc are produced, generally retaining small amounts of peroxide of iron and alumina.

CHAPTER XXXVII.

OLIVINE.

OLIVINE is one of the least fusible minerals known. According to Klaproth,* three crystals of olivine merely became attached together when exposed to the heat of a porcelain furnace. The olivine from Unkel melted to a greenish, lustrous, somewhat porous mass, with a radiated crystalline structure. Lava from Vesuvius also melted in the same fire. Olivine that is highly calcareous and ferruginous melts in an ordinary furnace.

This mineral is completely decomposed by sulphuric and hydrochloric acids, silica separating as a gelatinous mass.

Occurrence.—Olivine is the most characteristic constituent of basalt.† It occurs in many kinds of dolerite, but less frequently than in basalt, and not in such fine crystals. The coarse-grained crystalline dolerite does not seem ever to contain olivine; but when the rock consists of smaller particles it appears, first as isolated granules, and more abundantly as the rock approximates to true basalt. The dolerite of some localities contains olivine more frequently; as, for instance, some of the dolerite in Iceland; that of the immense blocks at the Ile de France; at other places the dolerite contains, chiefly, the ferruginous hyalosiderite. Olivine never occurs in wacke, even where it is in contact with basalt; probably because it has been decomposed. However, Freiesleben mentions distinct granules of olivine in a wacke dyke.‡ The largest masses of olivine occur in basaltic conglomerate more especially; but v. Leonhard observed globular masses of olivine, six inches in diameter, in the compact basalt at Rentières, in Auvergne; and equally large masses occur in the basalt at Unkel.§ The lava at Lancerote, and that in the Eifel, are par-

* Beiträge etc. i, 22.

† Forchhammer states that there is not any olivine in the basaltic rocks of the Faroe Islands.

‡ Magazin für die Oryktographie von Sachsen. i, 7.

§ Die Basaltgebilde, i, 199.

ticularly rich in olivine. South-west of Dockweiler, there are large masses of basaltic lava, in which olivine and very large augite crystals are so numerous, that the matrix in some places is the lesser portion of the rock. The occurrence of globular masses of olivine at the south-east margin of the crater, at the Dreiser Weiher, where they are very abundant in the volcanic sand, is very characteristic. These globular masses are surrounded by a crust of lava, not unfrequently enclosing fragments of clay-slate or grauwacke. I have examined full a hundred of these globular masses, but never found similar fragments imbedded in the olivine.

There is not the least doubt that these globular masses of olivine have been ejected from a crater now extinct. They could not, however, have been thrown out in a melted state; for it cannot be supposed they would have solidified to a granular crystalline mass during their brief passage through the air; and if they had been soft when they fell, they would have been flattened like the volcanic bombs at Vesuvius;* but they are never found with this form. The masses vary in diameter from 2 to 12 inches; and though, supposing them to have been thrown out in a melted state, the former might have solidified, this could not have been the case with the latter.† There would, therefore, have been a difference between them in structure; but no such difference is recognizable, the small masses being quite as crystalline as the large ones. The considerable difference between the melting point of olivine and that of lava, accounts for the presence of the olivine in it.‡

In this case there could not have been any fragments of clay slate in the olivine, but their occurrence in the crust of lava may be accounted for. The scoriaceous masses at the crater of the Mosenberg, the Falkenlei, &c. are full of such fragments, showing that the lava of the Eifel contained them even while in the craters. The fragments of clay slate in the crusts of lava upon the olivine

* Breislak states that these masses are so soft when they fall that they may be pressed flat, and L. v. Buch found that they might be pressed out or bent. But these masses are pear-shaped, which is never the case with the masses of olivine.

† In order to study the phenomena of cooling presented by large melted masses, I have cast basalt balls two feet in diameter. By comparing the time of cooling with that of the much smaller volcanic bombs, such as are found at the lake of Laach, I was at once convinced that these could not have been either melted or soft at the time they were thrown out.—Die Wärmelehre des Inneren unseres Erdkörpers, 1837, p. 502.

‡ The detached olivine crystals ejected from Vesuvius in 1839, are not likely to have been products separated from the lava.

may, therefore, either have been enveloped while the lava was in the crater, or have become attached to the soft crust after they had been thrown out. In the first case, if the lava was not sufficiently hot to melt these fragments of clay slate, still less could the olivine have been melted. These remarks are equally applicable to the large masses of olivine in the neighbouring lava blocks near Dockweiler, and also to the granules of obsidian found by v. Buch, in the streams of obsidian, near Icod de los Vinos, in Teneriffe. The olivine in the lava at Tinguaton, projects beyond the surface, like buttons. His opinion* is that they were not melted, but were retained by the viscous lava adhering to them while the surrounding mass flowed on to lower points. In the lava towards Sobaco† the olivine is less abundant at the lower points, and at the end of the stream is altogether wanting.

All these facts are indicative of the existence of the olivine in a solid state in the melted lava, and are quite inconsistent with the opinion that it has originated from the lava.‡

Formation,—Berzelius§ found olivine in the syenite, near Elfdalen; and chrysolite is said to occur in the granite, or syenite, between the Nile and the Red Sea, and at the Island Topazos.¶ A. Erdmann describes olivine¶ constituting a bed in gneiss. Hermann mentions its occurrence in talcose schist, at the Ural.** Its presence in a metamorphic rock is particularly remarkable, because it had hitherto been found only in volcanic and meteoric masses.

The occurrence of olivine in this rock renders it intelligible that lava penetrating through olivine beds in metamorphic rocks might carry up with it masses of olivine. As talcose schist, if it has not a direct sedimentary formation, can have been altered only in the wet way, the occurrence of olivine in this rock would seem to indicate that this mineral has been formed in the same manner. However, the possibility of its formation by fusion is not thereby altogether denied. Furnace slags sometimes present the form of olivine;†† however, it must not be forgotten that such slags, according to the analyses of Klaproth‡‡ and v. Walchner,§§ are

* Physikal. Beschreibung der canarischen Inseln, p. 303.

† Ibid. p. 306.

‡ In the German edition, ii, 681 et seq., this subject is more fully treated of.

§ Jahresbericht. vi, 302.

¶ Breithaupt.—Handbuch der Mineralogie, iii, 723.

¶ See p. 360, No. xii.

** See p. 360, No. xi.

†† Die Basalt-Gebilde, ii, 494.

‡‡ Beiträge, v, 222.

§§ Jahrbuch der Chemie. und Physik. xxxix, 77.

essentially nothing more than silicate of peroxide of iron, either without magnesia, or containing only from 1·3 to 1·9 per cent. magnesia. Their composition approximates somewhat to that of olivine :* their oxygen quotients are 1·08, 1·055, 0·899, 0·89 ; the first two corresponding with that of olivine tolerably well ; the latter two deviating widely from it. Since, moreover, these slags can scarcely be supposed to have lost bases, and since analysis always indicates the presence of peroxide of iron, while the unaltered olivine contains protoxide of iron, it follows that there is but slight similarity between the composition of these slags and that of olivine. Therefore, the only point of analogy between them consists in the mineralogical characters.

Composition.—The analyses of perfectly unaltered olivine, by Stromeyer, are best adapted for the determination of the normal value of the oxygen quotient of this mineral.

	I.	II.	III.
Silica	40·09	40·45	41·19
Magnesia	50·49	50·67	50·27
Protoxide of iron	8·17	8·07	8·54
Oxide of nickel	0·37	0·33	....
Oxide of manganese	0·20	0·18	....
Alumina	0·19	0·19	....
	99·51	99·89	100·00
O. Q.	1·049	1·042	1·00

I. Olivine from the basalt of the Vogelsberg, near Giessen.

II. Olivine from the basalt of Kajalthof, in Bohemia.†

III. Theoretical composition calculated from the previous analyses.

IV. Olivine from the basalt of } Rammelsberg‡ 1·037
Engelhaus, near Carlsbad

V. Olivine from the basalt of Ballen- } Baumann‡ 0·818
reuth, in the Fichtelgebirge.

The brownish colour of this olivine indicates incipient decomposition, in which a part of the bases have been removed, and thus the oxygen quotient reduced.

* See p. 360, No. xii.

† Stromeyer.—Jahrbuch für die Chemie und Physik. xliv, 265 et seq.

‡ Suppl. 4, p. 16.

§ Ibid. p. 14.

	Analyzed by	O. Q.
VI. Olivine granules from the Thjorsá lava at Hecla	Genth*	0.911
The pale yellow colour of this mineral indicates alteration, and the low oxygen quotient agrees with this.		
VII. Olivine from the doleritic lava of Fogo, one of the Cape Verde Islands.	Deville†	0.946
VIII. Olivine from the volcano Antuco, in the Chilian Cordilleras.	Domeyko‡	0.943
IX. Yellow olivine, from an olivine ball in the Dreiser Weiher.	Kjerulf§	0.968
X. Yellowish - green crystallized olivine, from the Fiumara of Mascali, at Etna.	Sartorius v. Walters- hausen||	0.990
XI. a. Olivine from the talcose schist of Sysserk, in the Ural.	Beck	1.040
XI. b. The same mineral.	Hermann¶	0.994
XII. Olivine—eulysite—constituting, together with augite and garnet, a bed in the gneiss of Tunaberg, in Sweden.	A. Erdmann**	1.093

This olivine consists of—

Silica	...	...	...	...	29.34
Protoxide of iron	...	...	...	...	54.71
Protoxide of manganese	...	...	...	...	8.39
Magnesia	...	...	...	...	3.04
Lime ††	...	...	...	...	3.07

It is characterized by the large amounts of iron and manganese, and the small amount of magnesia that it contains.

XIII. Chrysolite—oriental.	Stromeyer‡‡	1.062
XIV. Olivine from the meteoric iron of Atacama.	Schmidt§§	1.104

* Annal. der Chemie und Pharm. lxvi, 20.

† Bull. de la soc. géol. de France. Sér. 2, viii, 423.

‡ Annal. des Mines. Sér. 4, xiv, 187.

§ German edition, ii, 1495.

|| Ueber die vulkanischen Gesteine, p. 111.

¶ Journ. für prakt. Chemie. xlv, 222.

** K. Vet. Acad. Handl. of 1845, p. 15.

†† There is 5.12 per cent. lime in the mineral represented by VII. likewise.

‡‡ Loc. cit.

§§ Poggend. Annal. lxxxiv, 501.

XV. Hyalosiderite, from the Kai-serstuhl.	Analyzed by	Walchner *	1.152

Although few of the oxygen quotients from I to XIV are near 1; still this appears to be the normal value of the oxygen quotient of olivine that is entirely unaltered, and of chrysolite. There is no doubt that olivine whose oxygen quotient is less than 1, has already experienced some degree of alteration, consisting in elimination of bases. The peroxidation of the iron accompanying the decomposition of olivine renders the oxygen quotient higher, so that when the introduction of oxygen in this manner exceeds the diminution of oxygen consequent upon the elimination of bases it may happen that the oxygen quotient is increased by decomposition. This is more particularly to be expected in the case of ferruginous olivine, and in fact the oxygen quotients of the ferruginous olivine XII and XV are the highest, and Walchner's description of the latter mineral indicates that peroxidation of the iron had taken place. Perhaps the carbonate of magnesia, in the bitter-spar associated with these specimens of olivine, is a product of their decomposition.†

When on the contrary, the diminution of the amount of oxygen by elimination of bases, amounts to more than the increase of oxygen by peroxidation of iron, the oxygen quotient would be reduced. This may be expected in the case of the less ferruginous kinds of olivine, and it is precisely these whose oxygen quotients are less than the normal value. Therefore, by adopting 1 as the normal value of the oxygen quotient there will not be much deviation from the truth.

Olivine is characterized among other minerals by the presence of minute quantities of heavy metals. Thus it appears according to Stromeyer, that nickel is a constant constituent to the amount of 0.32 or 0.37 per cent. Walchner is of opinion that he has detected chromium in all specimens of olivine that he has analyzed. Berzelius‡ found in two specimens of olivine, oxides of tin and copper, barely 0.2 per cent.; in VI traces of oxide of copper were found besides oxide of nickel, and in XIV traces of arsenic.

Serpentine with the form of olivine.—The crystals described by

* Loc. cit. p. 65.—This is the only instance in which potash has been detected in olivine. It amounts to 2.79 per cent.

† Poggend. Annal. xliii, 669.—Lappe found bitter spar, greenish mica, and actinote between the granules of a mass of somewhat decomposed olivine from Greenland. Perhaps bitter spar and mica are products of the alteration of olivine.

‡ Ibid. xxxiii, 669.

Haidinger* as analogous to noble serpentine, correspond in form with olivine, and are probably pseudomorphs. The most characteristic specimens occur near Uhlen, in Norway. Quenstedt† showed that they correspond perfectly with olivine in form. Some of them are intersected throughout by bitter-spar. One crystal of more than four inches in length and three inches diameter, presents distinct indications of having been olivine originally; for the interior consists of perfectly unaltered olivine substance. It is quite evident that the alteration commenced at the surface, and bands of serpentine extend through the olivine, which becomes colourless, porous, and lastly, passes into serpentine. The brown bands which extend equally through both the rock and the crystals, appear to be olivine that is partially decomposed. The analyses of this mineral correspond with this description.

	I.	II.	III.	IV.
Silica	41.93	40.71	12.12	29.81
Magnesia	53.18	41.48	13.16	40.02
Protoxide of iron	2.02	2.43	0.77	1.25
Protoxide of manganese	0.25	....	....	....
Alumina	trace	2.39	....	....
Water	4.00	12.61	4.00	....
	101.38	99.62	30.05	71.08
O. Q.	0.969	...	....	1.018

I. Pseudomorphous crystals

Hefter.‡

II. Serpentine from Snarum

Scheerer.§

III. Amount of serpentine in I calculated in accordance with II, and the amount of water in I.

IV. Remaining portion of I corresponding in composition with olivine.

The crystal examined appears, therefore, to have been a mixture of serpentine and olivine, or imperfectly altered olivine. Therefore, all previous doubts as to this alteration are removed, and even the fact that olivine crystals have never been found so large as the serpentine from Snarum, ceases to furnish any valid objection to the possibility of this alteration; for Blum|| describes an

* Gilbert's Annalen. lxxv, 385.
† Poggend. Annal. xxxvi, 370
‡ Ibid. lxxxii, 516.
§ Ibid. lxviii, 328.
|| Jahrbuch für Mineral. &c. 1851, p. 660.

olivine crystal more than three inches long, three inches broad, and two and a quarter thick, which, as it is only a fragment, must have been much larger. G. Rose also mentions irregular shaped olivine crystals occurring in the talcose schist of the Itkul mountain in the Ural, which are sometimes as large as a man's fist. Judging from the analysis of villarsite by Dufrenoy, he is of opinion that it is olivine in a state of decomposition.

Decomposition of olivine.—From the examination of a great number of olivine balls in the neighbourhood of the Dreiser Weiher, I have come to the following conclusions as to the colour and decomposition of this mineral. The pale green-colored olivine appears to be least decomposed. When the green colour is darker the mineral is iridescent by reflected light, especially red and green. At these places there is, in some few instances, a thin gold colored lamina of mica. The dark green colour sometimes passes into a fine blue. The different colours originate from a progressive peroxidation of iron,* for where there are fine capillary fissures which facilitate the penetration of water, the dark green colour is found as a band at both sides, and often not thicker than paper. This dark green and the blue is also found at the exterior of the balls, while the interior is pale green indicating the progress of the oxidation from the surface. The last stage of oxidation is indicated by the ochre-yellow colour of the olivine, which passes into brick-red in the scorixæ rich in olivine, and at the same time the lustre and transparency are lost. In some balls of olivine all these colours may often be recognized in adjoining granules. I have never observed effervescence even in specimens of very decomposed olivine. Sometimes the granules of olivine are covered with a number of black or dark blue specks. It is only decomposed olivine that contains water, owing probably to the formation of hydrated peroxide of iron.

These diversities of colour are analagous to the coloring of steel, and still more to the coloration of sulphate of iron when oxidizing.

As the peroxidation of the iron in olivine progresses, the coherence of the mineral is reduced. Consequently the olivine balls that are much decomposed may generally be reduced to powder by a blow with a hammer, and for this reason the olivine occurring at the surface of basalt, frequently in large quantity, drops out after complete decomposition, leaving hollows.

* Compare Hausmann.—Ueber die Erscheinungen des Anlaufens der Mineral-Körper.—Jahrbuch für Mineral. 1848, p. 331.

Analyses of decomposed olivine.

	I.	II.	III.	IV.
Silica	52.00	42.61	49.2	53.6
Magnesia	37.75	48.86	16.8	18.0
Protoxide of iron	10.76	8.36	31.5	26.1
Peroxide of iron ...	....	....	1.4	0.7
Protoxide of manganese ....	....	0.15	....	....
Lime	0.12	0.22	....	....
Alumina ....	....	0.14	....	....
	100.62	100.34	98.9	98.4
O. Q.	0.639	0.939	0.548	0.469

Analyzed by

I. Disintegrated olivine, from Carlsberg, near Cassel } Klaproth.*

II. Ochre-coloured, opaque olivine without lustre, from the Wilhelmhöhe, near Cassel } Walmstedt.†

III. Olivine, much decomposed Rhodius.‡

From these two specimens of olivine, nearly half the bases have been eliminated; and the magnesia certainly to a greater extent than the protoxide of iron. It has already § been remarked, that olivine and corderite are among the few minerals which, containing silicate of magnesia, are, nevertheless, very liable to alteration. This, in the case of corderite, has been attributed to the conchoidal structure, and, in olivine, to the granular structure. Chrysolite, which does not present this structure, is not liable to undergo alteration. || It is certain that this structure facilitates the penetration of water; but when it is remembered that other minerals, rich in silicate of magnesia, such as mica, chlorite, etc., have a very perfect cleavage, which likewise admits of the penetration of water, and are not decomposed in this manner, it is evident that this fact alone is insufficient to account for the great tendency of corderite and olivine to undergo decomposition. Nor does the composition of these minerals furnish any elucidation of this fact;

* Beiträge, i, 118.

† Jahrbuch der Chemie. und Physik. xliv, 265.

‡ Annal. der Chemie. und Pharm. lxxiii, 216.—The relative quantities of proto- and peroxide of iron have probably not been exactly determined, for olivine that is so much decomposed would certainly contain more peroxide of iron than protoxide.

§ See ante, p. 283.

|| Walmstedt.—Loc. cit.—German edition, ii, 687.

for silicate of magnesia is combined, in corderite, with silicate of alumina, as in magnesian mica and in chlorite, and in olivine, with protosilicate of iron, as in these minerals, and still there is such a difference in the liability to decomposition.

There are many cases in which the state of aggregation of a substance has great influence upon the solubility. Metals with smooth surface dissolve less readily in acids than such as have rough surfaces. When solution has once commenced, and the surface has become roughened, it proceeds more rapidly. Polished iron or steel resists oxidation for a long time, but when it has once commenced, it progresses rapidly. There is no doubt that it is the rough surface formed in this instance, which favours the increasing oxidation, which goes on when the rust is removed without polishing the surface. For this reason, steel soon rusts again at the places which have become roughened by previous oxidation. The extent to which oxidation is increased when surface of contact is increased, is shown by iron reduced by hydrogen. There is as great difference between the oxidation of this finely divided iron, which inflames by contact with air, and that of polished iron, which, in a dry atmosphere, does not lose its lustre for years, as there is between substances of very unequal liability to oxidation. The sulphuret of copper, precipitated by sulphuretted hydrogen, oxidizes even upon the filter when it has been washed, while copper pyrites merely becomes colored at the surface.

These analogies between native minerals and substances prepared artificially, render it unquestionable that the tendency to decomposition in minerals which are similar in composition, is chiefly owing to their different states of aggregation. Smooth faces, absence of cleavage perpendicular to them, are the conditions which reduce the liability to decomposition. These characters are presented in a very high degree by mica, and hence its slight tendency to alteration.

CHAPTER XXXVIII.

MICA.

IN this mineral, which is one of the most remarkable products of alteration, *the chemical affinity of its constituents for those of the atmosphere, has become almost naught.

The influence of atmospheric agents is exercised upon all minerals to such a depth below the surface of the earth, as water is capable of penetrating. Minerals that were formed under such conditions that the atmospheric agents could not exercise any influence upon them, would, consequently, be liable to alteration when brought within the range of their influence.

In volcanoes the phenomena of mineral formation are either wholly independent of the atmosphere, or they are of such a nature that the constituents of the atmosphere take no share in them. For this reason lava, and all volcanic products that are not, by vitrification, rendered less liable to alteration, are decomposed with unequal degrees of facility when exposed to the atmosphere.

If the mica thrown out of craters, with other volcanic products, had been formed by fusion, this very durable mineral would be the only exception to this rule; for the mica occurring in the products of the extinct volcanoes in the Eifel, and the lake of Laach, does not present a trace of decomposition, even when its colour has been altered, as would appear to have been the case with the pinchbeck-colored mica. As mica is to such slight extent liable to alteration by atmospheric agents, it may be inferred that it has been formed under their influence, and is the result of their constant reaction upon a great number of minerals, which furnish the material for its formation.

The extraordinary divisibility of mica,† and its great durability, are, to a certain extent, inconsistent with each other. If felspar were equally divisible, it would certainly be decomposed within a very short time, owing to its comparative greater liability to decomposition than mica.

Minute divisibility is a character presented in a high degree by minerals that contain a considerable amount of magnesia.‡ Even where there is a transition of one mineral into another, there is

* See ante, p. 111.

† See ante, p. 112.

‡ See ante, p. 113.

frequently an increase in the divisibility simultaneously with an increase in the amount of magnesia. Thus, for instance, bronzite and hypersthene contain greater amounts of magnesia and protoxide of iron than diallage; and their capability of cleavage is far greater.* But even those kinds of mica which contain little, or no magnesia present a cleavage, that is, if anything, greater than that of magnesian mica. There does not appear to be any definite relation between the divisibility of mica and any particular constituent.

The great durability of mica is accounted for by its composition only in so far that it does not contain lime as an essential constituent, but only in very trifling amount. Those minerals, which, like wernerite, by reason of the large amount of lime that they contain, are very liable to alteration, become very durable when the lime is eliminated, and they are converted into mica. Othoclase does not contain lime; and, like mica, consists of silicates of alumina and of alkalies; but, nevertheless, the liability to decomposition is very unequal in these two minerals. Protoxide of iron, which, by its peroxidation in augite and similar minerals, greatly favours their decomposition, is a constituent of many kinds of mica to a considerable amount, but they are none the less durable than those kinds which are not ferruginous. Even when the protoxide of iron in mica passes into peroxide, the mica is only altered in colour.

If magnesia were in all instances a considerable constituent of mica, the great durability of this mineral might appear to be owing to the presence of silicate of magnesia, which is likewise present in the very durable minerals chlorite, serpentine, and steatite. But in potash mica the amount of magnesia is so small, that it cannot be supposed to contribute in any degree to the durability of the mica.

It is evident, therefore, that neither the extreme divisibility nor the durability of mica are at all essentially connected with the chemical composition; but that they are referable to the constitution of the silicates, or to peculiar isomeric conditions. Binoxide of tin furnishes an analogous instance; for, according to the way in which it is formed, it is either soluble or insoluble in acids.

The most diverse compounds may occur with the form of mica. The following table of maximum and minimum amounts of the several constituents of mica shows the great diversity that there may be in the composition of this mineral, and the contrast there is between this fact and the great uniformity of the physical characters.

* Köhler.—Poggend. Annal. xiii, 117.

		Minimum.		Maximum.
Silica	....	36 per cent.	....	71 per cent.
Alumina	....	6 „	....	38 „
Protoxide of iron	}	0 „	....	36 „
Peroxide of iron				
Magnesia	....	0 „	....	29 „
Potash	....	2 „	....	14 „
Lithia	....	0 „	....	5.7 „
Fluorine	....	0 „	....	10.4 „

Soda, which is not indicated as a constituent in the earlier analyses, has always been found in the more recent analyses, although in subordinate amount as compared with potash. In the analysis of mica and micaceous schist I have always found soda; and in one specimen of micaceous schist in larger amount than potash.

In conformity with the plan adopted by Rammelsberg,* I shall arrange the different varieties of mica according to their preponderating constituents into—

I. Potash mica.

II. Magnesian mica; in which magnesia is an essential constituent.

III. Lithia mica, characterized by the presence of lithia, and by its fusibility.

The greater number of varieties of mica contain water to the amount of 4 per cent.; very few are anhydrous. The presence or absence of water does not appear to be characteristic of any particular kind of mica; for the same kind of mica is sometimes hydrated, sometimes anhydrous. A specimen of mica from a mass ejected from Vesuvius, lost by ignition 0.75 per cent. according to Bromeis.† But a specimen of mica imbedded in augite, from a similar mass, did not, according to Chodnew,‡ contain either water or a trace of fluorine. A specimen of greenish mica, from an ejected mass in the tuff at the foot of Vesuvius, lost by ignition 0.165 per cent.

If the presence of water in mica were attributed to the pressure under which it was formed by fusion, this pressure must be supposed to have been maintained during the solidification; and this could not have been the case with the hydrated mica occurring upon scorïæ, which have solidified under the ordinary atmospheric pressure.

Knox § found, in silver-white mica, 1.33 per cent. bituminous

* Handwörterbuch, p. 260.

† Poggend. Annal. lv, 112.

‡ Ibid. lxi, 381.

§ Ann. de Chim. et de Phys. xxv, 187.

water, and traces of ammonia. Stein* extracted an organic substance,† by means of alcohol, from the lithia mica of Altenberg, in the Erzgebirge. Mica from a basaltic rock, in the lake of Laach, yielded 3·65 per cent. water, with an empyreumatic odour and alkaline reaction, when heated to redness in a retort; and at a still higher temperature it lost 1·25 per cent. more. Silver-white mica, from the gneiss near Aschaffenburg, gave 0·49 per cent. water, with faint empyreumatic odour and acid reaction; when more intensely heated in a platinum crucible, it experienced a further loss of 4·21 per cent. There is no doubt that the water obtained by heating mica would, in most instances, contain products of the decomposition of nitrogenous substances, with traces of hydrofluoric acid.

As it is impossible to assume the existence of organic substances in melted masses, those who adopt the opinion that mica has been formed by fusion, must suppose the organic substance to have been introduced by water subsequent to its formation. But if water has deposited organic substance, it is still more possible that it may have deposited inorganic substance, and thus have effected the formation of mica; for inorganic substances are far more abundant in water than organic substances.

Blum directs attention to the fact, that pseudomorphous mica has generally the colour of the mineral from which it has originated. Thus the lithia mica, originating from lithia tourmaline, has a peach-red colour; that originating from red pinite, is red; and that originating from green pinite, is green. The colours of the mica, and the augite, in the fassaite already mentioned,‡ correspond.

The greater number of varieties of mica lose lustre when ignited, and the colour changes. Colorless laminae of mica, heated to redness in a spirit-flame, become opaque, dull, and silvery. When more intensely heated in a platinum crucible, these laminae acquire a golden colour.

The alteration of colour in mica, when it is ignited, is owing to the evolution of fluoride of silicium, according to H. Rose. But as those kinds of mica which do not contain fluorine, or contain only mere traces of it, experience the same alteration of colour, the cause of this phenomenon must be sought in some other circumstance.

* Journ. für prakt. Chemie, xxviii, 295.

† These organic substances are a great obstacle to the preparation of lithia for artificial mineral water.

‡ See ante, p. 327.

At the lake of Laach two kinds of rock occur, in which mica is very abundant. The one is an altered basalt; the other is light-brown colored, and reddish-brown at the interior. Both contain a great number of augite crystals.* The latter rock appears to have originated from the former, by the peroxidation of the iron it contains. The mica in the former, has a greyish-black colour, and the thin laminae are translucent. The mica in the latter rock has a pinchbeck-brown colour. The former becomes pinchbeck-brown when ignited, the lustre is increased, and it then perfectly resembles in appearance the latter, which is not altered, either in colour or lustre, by ignition. It also resembles the mica upon the scoræ and rapilli of Leilekopf and Herchenberg, the colour of which is not altered by ignition. Therefore, the mica upon the altered basaltic rock undergoes the same alteration by ignition, as the mica upon the other rock appears to have undergone in the wet way. The fact that, when this greyish-black mica is ignited under charcoal-powder, it does not undergo any alteration of colour; and that the mica, which has become brown by ignition, acquires its original colour when ignited with charcoal-powder, sufficiently prove that the change of colour is owing to the oxidation of the iron. A similar reduction may be supposed to take place in the wet way, when a brown mica is exposed to the action of organic substances; but it would hardly be likely to take place in the air, the oxidizing action of which would exercise a compensating influence. Therefore, the greyish-black mica in the altered basaltic rock, which is partially exposed to water and partially to air, cannot have had a pinchbeck-brown colour. If it has been formed by fusion, it must have been under such conditions that atmospheric air was entirely excluded.

Therefore, pinchbeck-brown mica that was originally formed with silicate of peroxide of iron, or that has been formed in the course of time by the peroxidation of protosilicate of iron, cannot experience any essential alteration of colour by ignition.

Lithia mica when ignited undergoes the same changes as garnet and vesuvian.† It becomes perfectly decomposable by acids. Hence the inference, drawn from this fact, as to the origin of those minerals, are also applicable to lithia mica. This mineral contains nearly the same amount of silica as garnet and vesuvian; so that it may be supposed this effect is produced by the excess of strong bases. It has not been ascertained, whether other kinds

* These augite crystals are intimately and variously blended with mica.

† See ante, p. 83.

of mica are more easily decomposed by acids after having been ignited.

H. Rose* found that a specimen of uniaxial mica, was sensibly acted upon when digested for a considerable time with acids; but that, on the contrary, biaxial mica was not effected even by the strongest acids. Kobell† completely decomposed three specimens of uniaxial mica, that were not much acted upon by hydrochloric acid, by digestion with sulphuric acid, the silica being left in the state of shining, pearly laminæ. Two specimens of biaxial mica treated in the same manner were not sensibly acted upon. According to Stein,‡ lithia mica is completely decomposed by sulphuric acid; but only imperfectly by hydrochloric or nitric acids. Kersten§ found that two specimens of mica, from the granite of Marienbad, were completely decomposed by sulphuric acid; but it was not determined whether they were uniaxial.

A number of specimens of magnesian mica, from scorix at the Leilekopf and Herchenberg, which were analyzed by Bromeis, were likewise decomposed by hydrochloric acid, particularly after ignition. According to Chodnew|| and Kjerulf,¶ the mica from Vesuvius is decomposed by sulphuric acid almost completely. The latter experimenter states, that the residual shining, white laminæ, amounting to 0·807 per cent. of the mica, consisted of 0·207 alumina, and protoxide of iron, 0·165 magnesia, 0·165 potash, and 0·330 soda. According to Delesse, all mica from granite, that has a pinchbeck-brown colour, is completely decomposed by boiling hydrochloric acid, and that the silica retains the laminar form, presenting a white colour and pearly lustre. Micaceous schist is also decomposed to an unequal extent by sulphuric acid.

Occurrence and formation.—There is not, perhaps, any crystalline rock, in which mica does not occur at least sometimes. As an essential constituent it occurs in granite, gneiss, micaceous schist, etc.

I. In rocks belonging to the granitic group.

According to G. Rose,** white potash-mica occurs as irregular laminæ, sometimes as distinct rhombic plates; black magnesian mica occurs also as irregular laminæ, but more frequently than the former

* Gilbert's Annal. lxxi, 18.

† Kastner's Archiv. xii, 35.

‡ Journ. für prakt. Chemie, xxviii, 296.—Compare also C. Gmelin.—Gilbert's Annalen. lxiv, 371.

§ Jahrbuch für Mineral. &c. 1845, pp. 664 and 666.

|| Poggend. Annal. lxi, 382.

¶ Jahrbuch für Mineral. etc. 1851, 430.

** Zeitschrift der deutschen geol. Gesellschaft. i, 356.

as six-sided plates. Not unfrequently the brown varieties of mica are met with, regularly blended with the white mica, and in such a manner that the white mica surrounds the brown, and the cleavage of both are in a continuous plane. This mode of association may be recognized in almost every specimen of granite, in which both kinds of mica occur.* In gneiss the potash mica sometimes occurs in tolerably large crystals, either as isolated laminæ or united in sheets, streaks, and bands.† In augitic rocks and scorïæ, magnesian mica occurs very frequently as six-sided plates. Magnesian mica appears to have a much greater capability of crystalline development than potash mica; and, in that case, the occurrence of magnesian mica with a definite form, together with potash mica with indefinite form, might be accounted for. The small six-sided laminæ of dark brown mica, which are frequently met with in white mica, would appear, therefore, to have been crystallized from a mass which yielded chiefly material for the formation of potash mica, and but little material for the formation of magnesian mica. The crystalline development of magnesian mica is also frequently disturbed.

There are some peculiar features of mica laminæ ‡ which indicate a long continued mobility of the particles of very different constituents. Adopting the opinion that mica has been formed by fusion, this can be attributed only to a very gradual solidification of melted masses. The case is very different when it is assumed that the formation took place in the wet way. Every drop of water that penetrates a rock dissolves some portion of its substance,§ so that the mobility of the constituents of the rock would continue so long as it was penetrated by water. Magnesia and protoxide of iron, which are always present in mica to some extent, may, under such conditions, be extracted from a plate of potash mica by water, and accumulated at another part of the plate. In this way it is possible to imagine the formation of magnesian mica from potash mica. I have found that when laminæ of white mica from various localities were acted upon by hot hydrochloric acid, traces of protoxide of iron and magnesia were extracted, without in any degree diminishing the lustre of the mica. The carbonic acid in water would, in the course of a long period, produce the same effect as hydrochloric acid.

It will never be possible to trace such alterations in the com-

* German edition, ii, 1388 et seq.

† Naumann's *Lehrbuch der Geognosie*, i, 564 et seq.

‡ German edition, ii, 1389.

§ English edition, i, 58.

position of rocks experimentally; for when a mineral is removed from the place of its occurrence, the alteration that it might be subjected to there, is at once stopped. Therefore, the same mineral cannot be analyzed at different stages of its alteration. In plants, however, the transfer of inorganic substances may be traced experimentally. Staffel* found that the inorganic substances in the organs of the horse-chestnut, and the walnut trees are both qualitatively and quantitatively different at different periods of vegetation. In both trees potash preponderates during the spring, and towards the autumn it is replaced by lime. In the autumn there is the greatest amount of lime in the wood and bark; in the spring the leaves contain the largest amount of phosphoric acid, and in autumn the bark and wood contain the most.

I have endeavoured to show that in reference to the deposition of inorganic substances in plants and minerals, there is unmistakable similarity.† The above-mentioned investigations show, that in both cases there is an interchange of substances, and what is particularly remarkable, that the substitution of potash for lime, which is so frequent in minerals, also takes place in plants. In the latter case, indeed, this substitution is mutual; for in the plants mentioned, from spring to autumn there is a gradual substitution of lime for potash, and from autumn to spring a substitution of potash for lime. Such a reversal of the interchange of constituents may take place in plants because the organic acids exercise an influence besides silica and carbonic acid, which are alone concerned in the alteration of minerals.

It is not known in what state of combination the bases in plants exist; but the above-mentioned investigations show, that in so compact a substance as wood, potash and lime may be mutually substituted. If it is unquestionable that in this case, the interchange is effected by means of water constituting the sap of the plants, it is equally certain that the water percolating rocks may produce a similar effect; for many rocks exceed wood in porosity.

II. Mica occurs blended with other crystalline minerals.

1. Plates of yellowish mica several inches in diameter, with imbedded crystals of red garnet two lines in diameter, occur in New Hampshire, U.S. The hollows left when the crystals are removed, are sharply defined, and the impression of the striated

* Archiv. der Pharmacie. Ser. 2, lxiv, 26 et seq. These results agree with those previously obtained by Wolff.—Journ. für prakt. Chemie. lii, 122 et seq.

† German edition, ii, 891 et seq.

faces are distinctly recognizable. The prior existence of the garnet crystals is unmistakable, and the subsequently formed mica must have had such a degree of plasticity as to receive a perfect impress of them. The yellowish colour of the mica is owing to the presence of hydrated peroxide of iron, which forms thin incrustations upon the mica laminæ, and appears with a darker colour in the cavities where the garnet crystals are situated. The colour is not entirely removed by cold, or even boiling hydrochloric acid. Both before and after treatment with hydrochloric acid, grey cloudy spots in which the most delicate lines are grouped, in a brush like manner, in all directions, may be recognized by means of the microscope. There is no doubt that these spots are different from the substance of the white mica; but any further elucidation of their nature by chemical analysis is impossible. The hydrochloric acid, in which the mica is digested, contains peroxide of iron with traces of magnesia.

A quantity of these mica laminæ and a garnet crystal were exposed, in separate platinum crucibles, contained in a large clay crucible, to the influence of a strong blast for one hour. The mica laminæ did not present the slightest indication of fusion, but had merely become silvery and slightly translucent. The garnet, however, had been melted and appeared porous here and there. If the mica and garnet had been formed from a melted mass, the less fusible mica would have solidified before the much more fusible garnet. If the garnet crystals had been enveloped in melted mica substance, the garnet, would have been melted, and could not have produced a perfect impression in the mica. Consequently it is impossible that this mica can have been formed by fusion. By the fusion of the garnet, a small laminæ of mica became perceptible, the silvery edge of which projected beyond the black garnet mass. This mica must either have existed before the garnet crystallized, or have been formed simultaneously, or it is a product of the alteration of garnet. It is evident that the formation of crystals in the wet way, is not limited to any particular order of sequence. Therefore, if it is certain that the principal mass of the mica was formed after the garnet crystals, this laminæ of mica may have been formed before them.

2. A plate of yellowish mica, containing columnar crystals of black tourmaline, from one line in length, and as thin as the finest wire, to nineteen lines in length and one line thick, imbedded in all directions; from Haddam, in Connecticut.

The acicular crystals of tourmaline do not intersect where they

lie in the same plane; those that intersect are situated between different laminæ of mica. They never intersect at a right angle, but always at an acute, or obtuse angle.

A second plate of mica, from New Hampshire, seven inches long, four inches broad, and a quarter of an inch thick, contains, besides some small, black tourmaline-crystals, two short ones that are three and a half lines broad, and intersect at an acute angle. In both plates these crystals are situated in the plane of the mica laminæ. This is evident where the crystals have been removed, for the underside of the cavities are always formed by single, uninterrupted mica laminæ. In the first plate, these underlying laminæ generally appear striated, more rarely smooth; in the same manner the faces of the remaining tourmaline crystals, which are in the same plane as the mica laminæ, are either striated or smooth. In the second plate, the underlying laminæ are quite smooth; the lateral walls of the cavities, on the contrary, are striated, and the faces of the tourmaline crystals, which lie in the same plane as the mica laminæ, are likewise quite smooth; while the lateral faces of the tourmaline, projecting beyond the plate of mica, are striated. In the former instance, therefore, the tourmaline crystals are situated with their striated, lateral faces, partly in the plane of the mica laminæ, and partly intersecting this plane. In the latter instance, they have only the last-named situation.

The impressions of tourmaline crystals may be recognized, by means of the magnifying glass, in mica laminæ, that are thinner than writing-paper. Sometimes these impressions cross each other in such a manner that the sharp lines of two such impressions are continued through the point of intersection. This shows that the impressions are between different laminæ of mica, and that the thickness of these cavities is less than that of the thin lamina in which they occur. The tourmaline crystals that were in these cavities, may, therefore, have been no thicker than the thinnest mica laminæ. The cavities may also extend through several laminæ of mica; but even in this case, the tenuity of these tourmaline crystals must have been extreme.

The mica containing tourmaline, like that containing garnet, presents grey, cloudy, or brush-like markings, with the most delicate lines, which are not acted upon by hydrochloric acid; only the covering of hydrated peroxide of iron is dissolved. Perhaps these marks represent tourmaline substance that has been deposited after the formation of the mica. The priority of the formation of tourmaline is quite as certain as that of garnet.

I endeavoured to ascertain the relative fusibility of mica and tourmaline by an experiment similar to that above described, but did not obtain any decisive results. The tourmaline crystals were much altered by long-continued exposure to the blast, but the edges and corners were scarcely at all rounded, although some of the thin needles had stuck together.

The mica laminæ, also, had not only become silvery and dull, but had lost their elasticity; and their surfaces appeared curved and wrinkled. It would appear, therefore, that the tourmaline and mica were about equally difficult of fusion; so that the evidence that they cannot have been formed by fusion, is not so decided as in the case of mica and garnet.

A large copper-colored plate of mica, from Haddam, contains a great number of small, dark-grey, almost black particles without lustre, and surrounded, or covered, by a milk-white brittle mass, which, when detached by a knife, breaks up into thin laminæ. Some of these laminæ contain small, easily divisible granules, with black specks, or laminæ. Some of the granules are slightly magnetic. The laminæ dissolved in hydrochloric acid with effervescence, most readily with the aid of heat, a few flocks of silica were separated, and the granules, as well as some small, transparent, or milk-white laminæ remained. Some of these still presented the black specks. One lamina of this kind was an irregular hexagon, and two others presented this form less distinctly. The hydrochloric solution contained lime and magnesia in nearly equal proportions, a trace of peroxide of iron, but not any alkali. There is, here and there, between the layers of laminæ, a pale ochre-yellow mass that is dissolved by hydrochloric acid, and consists of peroxide of iron, alumina, carbonates of lime and magnesia.

In this instance there has, unmistakably, been, at the time the mica was formed, a separation of substances that could not enter into its composition. The carbonates of lime and magnesia are, unquestionably, products of the decomposition of the dark-grey particles; and, it is probable, that the six-sided mica laminæ are so likewise. This is rendered more probable from the fact, that the copper-colored mica is white where the dark-grey particles—perhaps augite or hornblende—are situated. By scraping the white parts with a knife, it is seen that there is a gradual transition from the white to the copper-colored mica.

The occurrence of hydrated peroxide of iron as a thin incrustation upon mica laminæ, is remarkable. This incrustation is not

unfrequent upon white, or light-colored mica. Freiesleben* mentions iron ochre that occurs in the interstices of mica laminæ, at Schwarzenberg, in Saxony. I have also found it between the most delicate laminæ of the white mica of Aschaffenberg, and other places. Although it might be regarded as a deposit from water that had penetrated the mica, its frequent occurrence upon white mica especially, which contains but little iron, would seem to indicate that it has been separated from the material from which the mica was formed. The formation of the highly ferruginous red garnet and black tourmaline shows that this material must have contained a considerable amount of protosilicate of iron. If there remained, over and above this, more that was capable of entering into the composition of white mica, the surplus must have been separated during the formation of the mica. I never found hydrated peroxide of iron between the laminæ of mica in the rapilli and scorïæ in the neighbourhood of the lake of Laach,† or in the ejected masses lying in the tuff at the foot of Vesuvius. This mica contains from 8·3 to 13 per cent. protoxide of iron, while the white mica contains only 4·5 per cent.; and it has taken into its composition all the iron present during its formation.

III. Mica laminæ occur upon altered, decomposed, or corroded faces of crystals of the most diverse kinds of minerals.

The mica laminæ upon such faces of augite and hornblende crystals have already been spoken of.‡ Rammelsberg also found laminæ of mica upon decomposed tourmaline.§

Several of the faces of triple crystals of chrysoberyl, from the micaceous schist of the Takowaja,|| are partially altered; and at these places present silver-white laminæ of mica, sometimes as large patches, sometimes as specks or delicate streaks, filling cracks. The alteration of chrysoberyl would appear, therefore, to consist in its becoming fissured at first, then brown-colored; and, lastly, converted into mica. In the midst of the mica there is unaltered chrysoberyl; and, at some parts, they are mixed together. One crystal was altered all round one half and covered with mica. This mica cannot originate from that of the micaceous schist; for, if so, it might be expected to occur also

* Geognost. Arbeiten, v, 24.

† Hydrochloric acid extracted in twenty-four hours, from the pinchbeck-colored mica of these scorïæ, only a trace of iron, while under similar circumstances it extracts from white mica an amount of iron sufficient to give it a yellow colour, and to furnish a precipitate with ammonia.

‡ See ante, pp. 330 and 351.

§ See ante, p. 262.

|| G. Rose.—Poggend. Annal. xlviii, 570; and Reise nach dem Ural, ii, 379.

upon the well-preserved, lustrous faces of the crystals. Moreover, the mica of this schist is brown;* and, therefore, different from that upon the altered faces of the chrysoberyl crystals. I have also found white mica upon the altered faces only, of the chrysoberyl crystals from Haddam, Connecticut. The chrysoberyl of Wiesenberg, in Moravia, has laminæ of mica inserted between the crystals.

The occurrence of white mica upon altered faces of chrysoberyl crystals, in the various localities where it occurs, indicates a uniform mode of alteration, with regard to which it is difficult to say how far chrysoberyl, that is so different in composition from mica, may have been concerned. An analysis of this mica is much to be desired. Perhaps it may contain glucina in the place of alumina. It will, subsequently, be shown, that minerals containing glucina are capable of being converted into mica.

In the Berlin collection of minerals there are corundum crystals, upon the disintegrated faces of which are situated laminæ of mica that also extend into the mass.

IV. Mica associated with hydrated minerals.

Diaspore sometimes contains six-sided plates of mica, generally yellow-colored, owing to the presence of hydrated peroxide of iron between all the laminæ; but transparent and colorless when this is removed.† In the Ural, brown iron-ore is much mixed with mica;‡ and it occurs in large nests at the boundaries of the micaceous schist.§ Below Erdbach, in the Westerwald, I found a layer of brown iron-ore that is penetrated throughout with laminæ of mica. In the porcelain earth of Bilin, in Bohemia, layers of silver-white mica alternate with layers of colorless quartz. In the porcelain earth of Aue I found some very minute laminæ of silver-white mica, that were so much in the interior of the mass that they could not be regarded as the mica of the granite. At those parts which may be scraped with a knife without coming upon granules of quartz, this mica must have originated from the larger felspar-crystals. As laminæ of mica are also found imbedded at these parts, they must have been, originally, imbedded in the felspar. But this is in contradiction to the fact, that they are most abundant where the felspar is most decomposed. Where granite is still attached to the porcelain

* Reise, etc., i, 484.

† Fielder.—Poggend. Annal. xxv, 325.—Compare also G. Rose.—Reise, etc., i, 254.

‡ G. Rose.—Reise, etc., i, 162.

§ Ibid. ii, 105.

earth, only brown mica is found in it. Also upon the faces of a large quartz crystal, there is a thin incrustation of kaolin, with a number of white laminæ of mica; and upon the faces of a fissure, in another quartz crystal, they are mixed with iron ochre. Upon the rough faces of a felspar-crystal, from Buchwald, in Silesia, I found a very great number of mica laminæ. As felspar is capable of conversion into mica,* there is no doubt that the laminæ of mica in this kaolin have, like it, originated from felspar.

V. Peculiar forms of mica.

Breithaupt† describes brown mica occurring as nodules and balls enveloped by pale-green asbestos, the fibres of which converge towards the centre. Outside this asbestos, and as a prolongation of the fibres, there is white mica with columnar structure, again surrounded by the same kind of brown mica that constitutes the nucleus. The nodular masses are tolerably frequent in a boggy meadow, in Moravia. In the Berlin collection of minerals I found irregularly-shaped columnar masses of mica, three or four inches long, and resembling achmite. F. Alger,‡ of Boston, describes quartz crystals covered with gold-colored mica, which also penetrates into the mass of the crystals in a vermicular form, owing to the contortion of the six-sided prisms of mica, which are often pierced by acicular crystals of rutile.

Now, since asbestos, occurring principally as narrow dykes in serpentine, a rock which has unquestionably been formed by alteration in the wet way, must be regarded as the product of a similar alteration, it is impossible to ascribe any other origin to the mica associated within and around the asbestos, in the above-mentioned instance.§

VI. Mica in drusy cavities and upon lodes.

The drusy cavities of the granite of Alabaschka contain mica, lithia-mica, etc.;|| in those of a greenstone schist at Harthau, in the Erzgebirge, mica occurs as an incrustation upon crystals of calc-spar, prehnite, and magnetic iron-ore;¶ and in the drusy cavities of a specimen of granite in the Freiberg collection of minerals, I found mica upon tourmaline crystals. In cavities of compact felspar from the micaceous gneiss at Arendal, mica crystals are found, and in the Barbo Valley they are found crowded

* See ante, p. 172.

† Paragenesis, p. 42.

‡ Silliman's American Journ. x, 77.

§ German edition, ii, 1401.

|| G. Rose.—Reise, etc., ii, 554.

¶ Naumann.—Erläuterungen, ii, 277.

together, traversing a mass of compact felspar.* In the neighbourhood of the Castle Augustusburg, in the Erzgebirge, there is a dyke consisting of hornstone, amethyst, fluor-spar, and quartz; the latter mineral forming small drusy cavities in which there are, besides very small quartz crystals, small silver-white crystals of mica.† Mica is found also in deposits of magnetic iron-ore and specular iron, copper pyrites, iron pyrites, cobalt glance,‡ and other ores.§ In such cases it is impossible to ascribe to the mica an igneous origin.

VII. Mica upon volcanic rocks.

At the Leilekopf, a cone of scorix near Brohl on the Rhine, that has been quarried for sand, mica sometimes occurs as laminæ and plates of an inch in diameter, between the rapilli. The inclined stratification of these rapilli, shows that they were thrown out of a formerly active volcano, and rolled down a sloping surface. It cannot be supposed that the mica was thrown out of the volcano mixed with the rapilli and scorix; for plates of mica consisting of delicate laminæ, and of such slight coherence, that they easily break between the fingers, would have been reduced to small fragments by rolling along together with the coarser masses they were mixed with. It would appear, therefore, that they have been formed at the places where they are found. At one place in the sand quarry, there is a frequent alternation of layers several inches thick, consisting of rapilli-sand, with others consisting of rapilli as large as hazel nuts. It is among the latter that the masses of mica are abundant, and not in the loose sand. A block that has fallen down, and consists of loosely adherent rapilli, contains a great number of plates of mica, between the laminæ of which are thin layers of carbonate of lime, with traces of carbonate of magnesia. However far the separation of the laminæ is carried the surfaces still effervesce with acids. The rapilli likewise effervesce copiously, not only in this block but at all parts of the quarry. Therefore, they have been permeated by water, that deposited carbonate of lime. This carbonate is in part a product of the decomposition of silicate of lime in the rapilli, in part derived from loess by which they are covered at one place. This deposition of lime as carbonate shows unmistakably the influence of water percolating the rapilli. But wherever water has such ready

* Weibye.—Archiv. für Mineralogie, xxii, 479.

† Kaden.—Naumann's Erläuterungen, ii, 85.

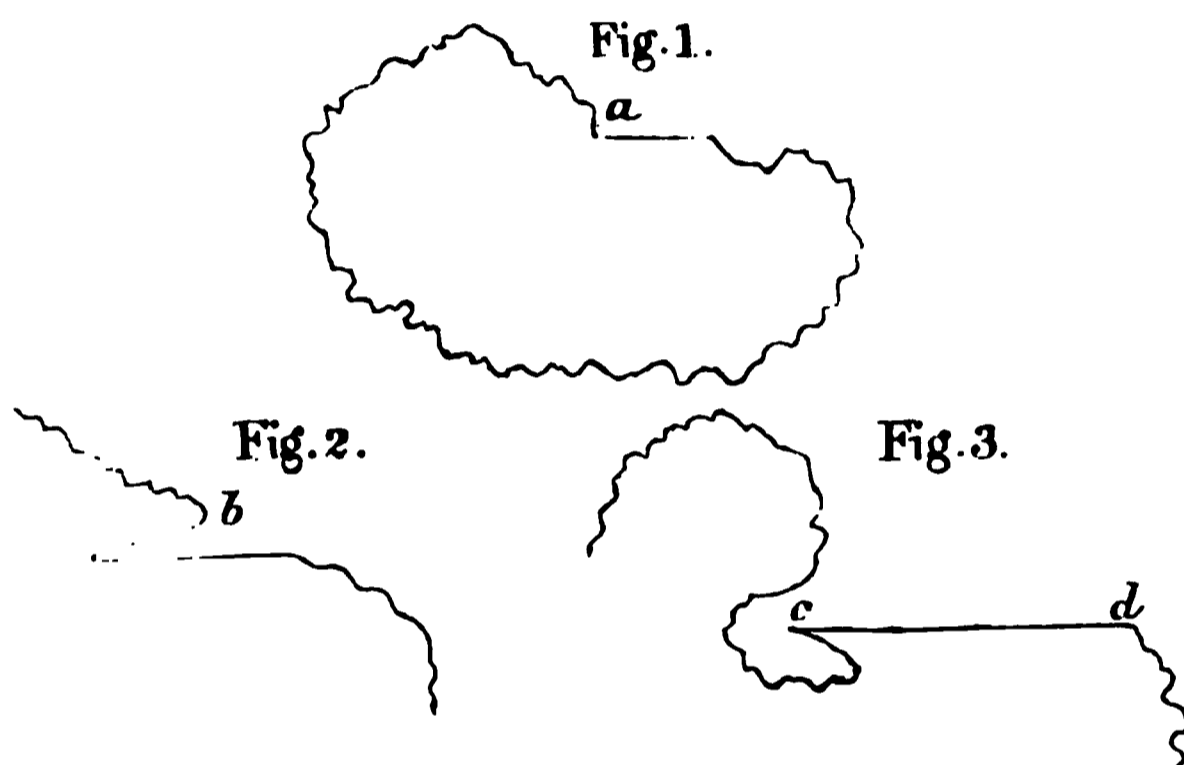
‡ Hausmann.—Handbuch der Mineral. Ed. 2, i, 680.—In some of the lodes at Schneeberg mica is found.—Naumann.—Geologie, i, 743.

§ Scherer.—Breithaupt's Paragenesis.

access, mica may be formed, and as will subsequently be shown, its formation from basaltic substances, or from augitic lava is very easily intelligible, lime being always eliminated at the same time and appearing as carbonate.

At the Herchenberg and at the Kunksköpfen, near Wassenach, the mica does not occur between the rapilli, but only in the spongy scorïæ scattered through them.

At these and other places in the neighbourhood of the lake of Laach and the Eifel, masses of scorïæ about the size of fig. 1, and at the Leilekopf, larger pieces are found, with plates of mica *a* that appear as if pressed into the soft mass.



In another fragment of scoria, fig. 2, there was a plate of mica *b*, the laminæ of which opened at the opposite end like a fan. In a third piece fig. 3, there was a small drusy cavity at *c* into which the substance of the scorïæ extended as thin as paper, and covered with a lamina of mica *cd*. When these laminæ of mica are detached, the even, or somewhat convex surfaces of the scorïæ underneath appear as smooth impressions of them. When the scorïæ are very porous, the pores opening on these surfaces under the mica laminæ are rather widened, and sometimes when the substance of the scorïæ is very porous, the undermost lamina of mica is perforated at some places, and the substance of the scorïæ extends some way into the holes. Besides the larger laminæ of mica there are microscopic particles of mica in the scorïæ.

A piece of micaceous basalt from the lake of Laach was exposed to a moderate red heat in a crucible. The only recognizable alteration, was the copper colour acquired by the mica plates.

The crucible was then brought to such a temperature that the basaltic substance melted. When cold it presented unequal sized drusy cavities. The mica which projected beyond the melted basalt had lost its lustre almost entirely, but when the outermost lamina of mica was detached the next one had much greater lustre. At some parts the laminæ of mica could be detached as easily as before the ignition, at other parts the laminæ appeared to have been stuck together. When the melted mass was broken in two, the mica at the interior presented its full lustre. It was, after this second ignition, gold-colored, with brownish spots. The laminæ of the plates of mica at the interior could be detached almost as easily as in the mica that had not been ignited. The plates were neither bent nor cracked, but presented just the same characters of position as in the unmelted basalt. Two drusy cavities contained mica in the same manner as it occurs in the drusy cavities of volcanic scoriæ.

This experiment shows that the mica in this basalt is much less fusible than the matrix, and, therefore, that it may have existed in the formerly melted mass. Even the alteration of colour that it presents when ignited may be owing to the peroxidation of iron that had, in the course of time, been reduced to the state of protoxide by means of organic substances in the water percolating the rock. However, it is more probable that this mica is a product of the alteration of basalt, as will be shown subsequently.

2. A piece of brown, earthy, porous scoria with gold-colored laminæ of mica, became very compact after fusion; the surface only appeared slightly porous. However, the mica laminæ were not melted, but only slightly agglutinated, so that they could scarcely be separated by a knife.

3. A piece of grey, earthy, and rather compact scoria, with pinchbeck-brown mica was perfectly melted. The mica was less altered than in the previous experiment; only the outer lamina of a plate of mica that adhered to the crucible, had lost its lustre. The laminæ could be easily separated with a knife.

The similarity of these two scoriæ with that obtained by artificial fusion, their porous and wholly uncrystalline character indicate very rapid solidification. As there are no grounds for supposing that the heat by which they were melted originally, was greater than in the above experiments, the mica imbedded in them would not have been melted, and then crystallized as the mass cooled. Although it is possible that while a melted mass is soft there may be a production of substances much less fusible than

the matrix, as appears to be the case with leucite;* still in the case of these micaceous scoriæ, the mica being so much less fusible, would have solidified at the moment it was formed, and this is inconsistent with the form in which the mica occurs in these scoriæ. Consequently it must be admitted that the mica in volcanic scoriæ has, for the most part, been formed after their solidification by an alteration in the wet way. It is only mica that does not change colour when ignited, that can have existed in the melted masses in the interior of the volcano.

4. Two plates of white mica an inch in diameter, were laid between powdered basalt from the lake of Laach, and intensely heated in a crucible. The basalt melted, forming, when cold, a compact, slightly porous mass. Towards the upper surface the drusy cavities were larger and more numerous. Both plates of mica remained in the same places. The lower one had formed at one end an even bed in the basalt, at the other end was a cavity of more than half an inch diameter. Small laminæ of mica had been detached from the plate and imbedded in the basalt; some of these were in small drusy cavities. The colour had become gold-yellow, and the lustre was almost lost. No sign of fusion could be detected in the mica; the laminæ were agglutinated only where they were in contact with the basalt, and might be detached as easily as before ignition, although they had become somewhat more brittle.

5. The last experiment was repeated with fresh basalt powder, in the midst of which was placed a plate of mica. The result was much the same as in the former instance. The plate of mica was situated upon the surface of the perfectly melted basalt, and was covered with only a very thin layer of it, so that the basalt must have been so liquid as to admit of the mica rising to the surface.

The opinion that the mica in scoriæ has been formed by igneous action after they were thrown out of the crater, must, for the reasons already mentioned, be rejected as untenable. Therefore, it can only be supposed that this mica existed in the crater previously, or was formed there by fusion, or was formed in the wet way after the scoriæ were thrown out.

The experiments 4 and 5 show that mica may be enveloped in melted lava when it penetrates micaceous rocks. The impressions of thin laminæ of mica upon, and in scoriæ, and the smooth surfaces underneath them indicate a very liquid condition of the lava.

* See ante, p 229.

When detached masses of such lava were ejected, the rapid cooling during their passage through the air, gave rise to the scoriaeous and perfectly uncrystalline structure.

If the mica had been formed from the lava solidifying slowly in the crater of the volcano, masses of it would have been detached and ejected when it had become solidified, and before the surrounding mass was solidified. So that it would be supposed the mica was formed within the crater by slow cooling, and outside the crater by rapid cooling. It would be only by a rare concurrence of circumstances that the masses thrown out, would consist of crystallized mica and perfectly amorphous matrix.

Bromeis analyzed some pale pinchbeck colored mica out of two specimens of scorix from Herchenberg and obtained the following results:

Silica ....	....	....	....	42.89	} 71.41
Alumina ....	....	....	....	6.09	
Magnesia ...	....	....	...	24.33	
Peroxide of iron	....	....	....	10.59	13.34
Lime ...	....	....	....	0.76	0.64
Potash ....	....	....	...	13.15	9.86
Soda ....	....	....	....	0.36	1.35
Water (<i>ammoniacal</i>) ....	....	....	....	2.30	3.40
				100.47	100.00

This mica undergoes but little alteration of colour when heated; therefore, it may have been exposed to the influence of volcanic heat; but the presence of water and of organic substances does not agree with this opinion.

The amount of alumina in this mica is less than has been met with in any other instance. Its composition is of such a kind that it may probably be a product of the alteration of augite similar to that from the Rhone,* supposing that the lime had been displaced by magnesia and potash.

Monticelli and Covelli† have instituted observations as to the occurrence of mica in the masses ejected from Vesuvius in the years 1821, 1822, and 1823.

The lava of 1821, consisted of leucite, augite and mica. That of February 26th, 1822, contained besides conglomerated masses of leucite and fragments of augite crystals, fragments of brownish

* See ante, p. 331, No. i.

† Der Vesuv.—German translation, 1824.—Mica is merely accidental in the lava of the Italian volcanoes.—Jahrbuch für Mineral. etc.

lustrous mica. The sand thrown out on the 26th and 27th February, 1822, contained fragments of shining, black laminæ of mica. The several fragments projected to a distance of two miles from the crater, also contained, besides leucite and augite, a small quantity of laminæ, and six-sided prisms of mica. The fine sand scattered to considerable distances all round the crater, also contained fragments of mica. A ball, from a foot to a foot and a half diameter, consisting of solid fragments of augite and green mica, with vitrified fragments of lava, contained in the interstices, very thin lustrous laminæ of reddish-yellow mica.

It is impossible to suppose that fragments of mica crystals have been formed during the solidification of the masses in which they occur; they would appear rather to have been of prior origin. The thread-shaped particles of the sand show unmistakably that they were thrown into the air in a liquid state and were suddenly solidified, and there are no grounds for supposing that under these conditions, mica could have been formed. Consequently the mica occurring in the volcanic products of the years 1821 and 1823 does not afford any evidence of having been formed during the solidification of these masses.

Blum informs me, that he found in a bomb, thrown out from Vesuvius during the eruption of the 1st April, 1835, laminæ and crystals of mica, which, when detached from the matrix, left even surfaces as in the above-mentioned scorïæ.* There is no doubt that this mica could not have been formed either in the wet way after the mass was thrown out, or during its solidification, so that it can only be regarded as having a prior existence.

In the above-mentioned greenish mica from the tuff at Vesuvius, Kjerulf found a six-sided nucleus corresponding to the exterior form. It appeared to consist of the same kind of mica as that surrounding it, and seated upon it were a number of small, transparent, hard granules, which were not acted upon by acids and appeared to be quartz. The six-sided outline of the nucleus was repeated several times upon some of the laminæ, in lines marked by these granules. Outside the nucleus also, there were a few isolated granules. In the nucleus were hard, black granules presenting lustrous faces of cleavage, and, when the mica was decomposed by sulphuric acid, they remained unaltered; they appeared to be augite.

This rock contains a considerable amount of mica and olivine; it effervesces copiously with acids, which extract alumina, a little

* See ante, p. 381.

iron, much lime and magnesia. Whether these alkaline earths are products of decomposition, or whether they originate from the carbonates in the tuff cannot be determined. As the mica in these masses does not change colour when ignited, and experiences only a very slight diminution of weight, it would seem that it had a prior existence in the volcano.*

It cannot be expected that mica, which has been enveloped in lava or scorïæ, would, when heated, evolve water or change colour. It is, therefore, very desirable that all the mica from Vesuvius should be subjected to this test. It has already been mentioned that the mica from masses ejected from Vesuvius does not experience any, or at most, a very slight diminution of weight when heated. I have also found that mica from Vesuvius does not experience any change of colour by ignition, and Bromeis and Chodnew did not find any fluorine in it. Although these characters are not inconsistent with the opinion that the mica, in the masses ejected, has been exposed to the influence of volcanic heat, still, in accordance with the above remarks,† this cannot be unconditionally inferred.

Besides the blocks of micaceous basalt lying upon the former bottom of the lake of Laach, there are other blocks of a more compact basalt without any mica.‡ Assuming the igneous origin of mica in this rock, this difference cannot be attributed to the rate of solidification, for the more compact rock certainly did not solidify more rapidly than the less compact, porous rock. This circumstance is totally opposed to the opinion that the mica is of igneous origin, and is quite consistent with the opinion that its formation was subsequent to the solidification of the matrix, and was effected by water, which would evidently penetrate the porous rock more readily than the more compact one.

Mica is generally a rare constituent of basalt; so that the occurrence of such large quantities of mica in the basalt of the lake of Laach must be ascribed to peculiar circumstances.

I have already § pointed out several localities in which micaceous basalt is found; but the rock is, in every instance, altered or converted into wacke. I have also found globular masses of

* The way in which crystallized substances imbedded in lava have been formed, has been fully treated of by Breislak.—*Lehrbuch der Geologie*, German translation, iii, 254.

† See ante, p. 384.

‡ See ante, p. 381. With regard to the origin of these blocks, see German edition, ii, 1413 et seq.

§ German edition, ii, 1417.

highly micaceous rock, similar to that at the lake of Laach, upon the margin of the Gemünd and the Winfeld Maar, near Daun, in the Eifel; and at Hohenfels, in the Essing Valley, I found a very micaceous lava.

It cannot be doubted that the mica in these, and other basaltic rocks, is a product of alteration. If it were formed during the solidification of the rocks, it would be found, not only in those which are decomposed, but also in those which are fresh and unaltered.

The following analyses of mica from basalt, and from Vesuvius, show that it is always magnesian mica.

	I.	II.	III.	IV.	V.
Silica	44.63	43.02	39.75	40.91	44.63
Alumina	16.48	16.85	15.99	17.79	19.04
Peroxide of iron	11.32	11.63	8.29	11.02	4.92
Magnesia	19.06	18.40	24.49	19.04	20.89
Lime ...	..	0.71	0.87	0.30	..
Potash	} 9.75	8.60	8.78	9.96	6.97
Soda		1.15	..	..	2.05
Titanium	trace	trace	..	..	..
Loss by ignition ....	..	..	0.75	..	0.17
	101.24	100.36	98.92	99.02	98.67

	VI.			VII.
	a.	b.	c.	
Silica	43.10	43.10	...	44.90
Alumina	15.05	14.56	0.49	18.71
Peroxide of iron	13.25	22.53	0.73	9.09
Magnesia	10.82	10.28	0.54	7.14
Lime	0.81	...	0.81	12.90
Potash	4.62	4.62	...	0.68
Soda	0.82	0.82	...	0.68
Titanic acid (<i>impure</i>)	1.03	1.03	...	...
Loss by ignition	1.50	1.50	...	...
	101.00	97.44	2.57	

I. and II. Mica from the basalt of the lake of
Laach.

Analyzed by
Bromeis.

III. Crystallized, pale yellowish-green mica, from one of the ejected masses at Vesuvius.	}	Analyzed by Bromeis.*
IV. Blackish-green crystallized mica, im- bedded in green augite, among the ejected masses at Vesuvius.		Chodnew.†
V. Mica from Vesuvius		Kjerulf.
VI. Brown mica from a black augitic lava block at the Weinfeld Maar.	}	Kjerulf.
a. Analysis of the mineral as a whole.		
b. Portion decomposed by sulphuric acid, with separation of silica as white laminæ with metallic lustre, mixed with some green laminæ or granules.		
c. Green laminæ separated from the silica, and decomposed by hydrofluoric acid.		

Perhaps these laminæ were remains of augite, and in that case *b* would represent the true composition of the mica.

The correspondence between I and V, especially when the alumina and peroxide of iron are regarded as mutually replaceable, is sufficient to admit of the inference that the mica represented by these analyses originated in the same manner. The mica represented by I was dark-grey and became yellowish-brown by ignition, evolving at the same time 1.75 per cent. ammoniacal water; that represented by II became pinchbeck-brown by ignition, and evolved much ammoniacal water. On account of the deficiency of material the alkalis could not be estimated for I. The minerals represented by III and IV differ in experiencing but very slight loss by ignition. It is uncertain whether these specimens of mica were originally free from water and organic substance, or whether these substances had been expelled by volcanic heat. The mica represented by VI, is characterized by the considerable amount of iron, and the small amount of magnesia. However, there are some kinds of basalt that contain as much peroxide of iron as this mica.

A comparison of the composition of these varieties of mica with that of basalt,‡ shows a striking similarity. The conversion of the one into the other would appear to consist merely in substitution of magnesia § and of potash || for the lime in basalt. Water

* Poggend. Annal. lv, 112.

† Ibid. lxi, 381.

‡ No. VII.—Basalt from Wiekenstein, analyzed by Löwe.

§ English edition, i, 13, No. 16.

|| Ibid, p. 3, No. 5.

containing carbonate of magnesia and carbonate of potash may, therefore, effect the conversion of basalt into mica. It has already been shown that labrador and augite, the principal constituents of basalt, may be converted into mica.*

Altered augite, from the lake of Laach, sometimes contains alkalies.† If the mineral was originally aluminous, the bases eliminated must have amounted to more than the alkalies introduced. In the same way that alkalies were introduced into this augite by means of water, and its composition brought near to that of mica, it is probable that the augitic matrix was also converted into the micaceous rocks at the lake of Laach. Therefore, the conversion of basaltic rock into mica consists, simply, in the decomposition of silicate of lime by magnesian and potash salts; and, perhaps, also a partial conversion of silicate of soda into silicate of potash.‡ According to my analysis of the water of the lake of Laach, it contains the carbonates of magnesia and potash which effect this alteration, and also, in considerable amount, the carbonate of lime, which results from the alteration.

VIII. Mica, from furnace slags.

The occurrence of six-sided prismatic crystals of a micaceous substance, in old slags from a copper-furnace, at Garpenberg, in Sweden, appears to furnish evidence of the possibility of mica being formed by fusion. This substance consists, according to Mitscherlich,§ of:—

Silica	....	....	....	....	47·31
Alumina	....	....	....	....	5·74
Peroxide of iron			....	....	28·91
Oxide of manganese			....	....	0·48
Magnesia	....	....	....	....	10·17
Lime	....	....	....	....	6·23
Potash	....	....	....	....	1·05
					<hr/>
					99·89

The difference between the composition of this substance and that of all other kinds of mica, consists in the large amount of lime; for this substance never amounts to more than 1 per cent.; and, in most instances, mica is quite free from lime. According to Bredberg,|| the formation of this substance may be attributed to the action of calcareous fluxes upon the mica, associated with the ores smelted at Garpenberg.

* See ante, pp. 277 and 327.

† See ante, pp. 305 and 328, No. IV.

‡ See ante, p. 65, No. 38.

§ Abhand. d. k. Acad. d. Wiss. zu Berlin, 1822 and 1823.

|| Jern Kontoret's Annal. 1826, i, 155.

It is questionable whether a substance containing so large an amount of lime and so small an amount of potash can, with any propriety, be included among the varieties of mica. Augitic lava always contains lime; and if the mica occurring in it has been formed by fusion, it might be expected that it would have contained calcareous mica analogous to that found in the Garpenberg slags. But the analyses of this mica, already quoted, show that it never contains more than traces of lime. If the micaceous substance in the Garpenberg slags originates from the mica of the ores, its presence in the slag would not have any reference to the formation of mica; for it is quite possible that in the smelting process, the potash of the mica may be replaced by lime, in the same manner that, at a high temperature, lime displaces the greater part of the potash from felspar,* and all the alkalies from lithia-mica. If the mica associated with these copper ores was fusible only at a very high temperature, this alteration would be the more probable.

A mixture of potash mica and carbonate of lime, was intensely ignited for several hours in a platinum crucible, the mass washed, the lime precipitated by carbonic acid, and the filtrate evaporated to dryness. A residue was thus obtained which had an alkaline reaction. On repeating this experiment with a larger quantity, potash could be recognized in the residue, by means of bichloride of platinum. Micaceous granular limestone gave similar results. The introduction of lime could not be decisively proved by experiment, because the mica in the rock contained some silicate of lime.

These experiments show, that neither granular limestone, nor the mica associated with it can have been formed by the way of fusion. Whether sedimentary slate and limestone rocks were simultaneously converted into micaceous schist containing limestone, or whether sedimentary or granular limestone was protruded into micaceous schist; in any case, if the rock had been exposed to the influence of heat, the potash of the mica would have been displaced by lime, and removed by water subsequently penetrating the mass. But the mica from granular limestone, at Pargas, contains, according to Svanberg,† 8.45 per cent. potash, and only 1.03 per cent. lime; even this minute quantity may originate from an admixture of granular limestone.

When it is remembered that the micaceous schist, containing limestone, is always distinctly stratified; passing into pure gra-

* See ante, p. 163.

† Berzelius Jahresbericht, xx, 235.

nular limestone, or ordinary micaceous schist, and is of very frequent occurrence in the Austrian and Swiss Alps, as well as in the Alleghany mountains, U. S., where it seems to play an important part,* it must appear evident that the mica it contains is not of igneous origin. Indeed, all the phenomena described above, tend to show that mica is not, in any instance, formed in such a manner.

Mica, with the forms of other minerals.

In treating of those minerals which are susceptible of conversion into mica, the pseudomorphous states of mica have already been described. The following data tend to elucidate the process of alteration in those minerals whose products have been examined chemically.

Mica, with the form of felspar.—The following table contains the results of analyses of specimens of mica alluded to previously, and furnished to me by Blum:—

	I.	II.	III.		IV.	
			<i>a</i>	<i>b</i> ‡	<i>a</i>	<i>b</i>
Silica	[67·95†]	[60·51]	55·18		48·19	
Alumina	12·76	25·00	19·87	19·82	30·17	
Peroxide of iron	2·09	7·77	13·30	13·29	5·69	} 34·66
Oxide of manganese ....	....	...	trace		....
Lime ....	....	....	1·18		....
Magnesia ....	....	trace	0·17		0·42	0·47
Potash	} 16·66	3·92	5·87	5·87	8·13	8·13
Soda		0·15	1·35	1·35	0·35	0·35
Loss by ignition	0·54	2·65	0·31‡		1·56	
	100·00	100·00	97·23		94·51||	

* Naumann's Geologie, i, 668.

† The numbers inclosed in brackets were obtained by subtraction.

‡ This mineral lost a considerable quantity of water at 212° F. The powder was yellowish-white before ignition, brownish after ignition, owing unquestionably to peroxidation of iron.

§ The powder, when treated with hydrofluoric acid, evolved an odour of musk.

|| I was unable to ascertain the reason of the considerable deficiency of 5·49 per cent., owing to want of material. The amounts of alumina and of peroxide of iron in *a* and *b* correspond to within 1·2 per cent., which is not a considerable difference when it is remembered that pseudomorphous minerals frequently present great differences in composition at adjoining places. No trace of magnesia remained. The amount of fluorine in potash-mica rises to 3·3 per cent.; in the lithia-mica of the Zumwald, to 6·35 or 8·16 per cent.; in that of Tuschakowa, to 10·44 per cent. It is probable, therefore, that the deficiency in the analysis IV. represents fluorine.

	V	VI	VII
SiO ₂	47.11	45.19	48.00
Al ₂ O ₃	34.22	33.80	34.25
FeO & Fe ₂ O ₃	1.76	4.47	4.50
CaO & MgO, with H ₂ O	2.11	2.58	0.50
Na ₂ O		0.23	—
K ₂ O	7.11	7.35	8.75
Fluorine	1.10	0.29	—
Total	93.41	91.71	106.25
	97.31	96.25	97.25

- I. Amorphous mass from Wamersbach.
- II. Mica representing from the previous mineral.
- III. Fragment of the alteration of kiesel. from Finbo.
a. Analysis of the mineral as a whole.
b. Constituents dissolved by hydrofluoric acid.
- IV. Mica with the form of kiesel: probably from Lönitz,
in Siberia.
- V. Mica from the neighbourhood of Fahlun. H. Rose.*
- VI. Mica from Uivak. H. Rose.*
- VII. Mica from granite in Siberia. Klapproth.†

There was not enough of the mineral II, for the direct estimation of silica and to test for fluorine. If, as is probable, it contained fluorine, the amount of silica would be less than appears. The presence of fluorine in the mineral represented by III, is still more probable, for the close correspondence of the amounts of alumina and peroxide of iron in III. a and b shows that the considerable deficiency of 2.77 per cent. does not arise from error in the analysis. Unfortunately the quantity of this mineral was too small to test for fluorine. There is no doubt that the mineral represented by III. is mica and not steatite as Blum supposed;‡ for it contains but a very small amount of magnesia, which is the essential constituent of steatite. However, the defective cleavage shows that it is not perfect mica. It contains a larger amount of silica than any potash mica hitherto analyzed, and the white mica of Monroe, which, according to Brewer,§ contains 50 per cent.

* Poggend. Annal. i, 79 and 83.

† Beiträge, v, 73.

‡ See ante, p. 173.

§ Dana's Mineralogy, p. 359. — The large amount of water in this mineral — 1.10 per cent. — also indicates that it is not normal mica.

silica is the only one that approximates to it in this particular. However some kinds of lithia mica approximate still nearer to it, since they contain as much as 52·25 per cent. silica.

A comparison of the normal composition of felspar, F, with that of the mica M, represented by III, and a calculation of the substances eliminated and introduced will serve the purpose of illustrating the conversion of felspar into mica.

	F.			M.
Silica	65·21	—	10·03	55·18
Alumina	18·13	+	1·74	19·87
Peroxide of iron ....	....	+	13·30	13·30
Alkalies	16·66		9·44	7·22
Lime ....	....	+	1·18	1·18
Magnesia ....	....	+	0·17	0·17
Loss by ignition ....	....		....	0·31
	100·00			97·23

This alteration consists essentially in the elimination of 10·03 per cent. silica, with 9·44 per cent alkalies, proportions almost corresponding to simple silicate; and introduction of 13·3 peroxide of iron. The introduction of peroxide of iron is accounted for by the reaction between silicate of alumina and hydrated peroxide of iron; * the partition of the silica between the two bases, and the formation of a double silicate.

I do not take into account the minute quantity of alumina that would seem to be introduced, because such minute differences may be owing partly to variation of the amount of this earth in different kinds of felspar, partly to errors in the analyses. Nor do I take into account the small amounts of lime and magnesia, which are not essential constituents of mica, and may be derived either from the felspar or from the water by which alteration was effected.

The large amount of iron in III is not remarkable, for in potash mica it is even larger; thus brown mica from Cornwall was found by Turner † to contain 27·06 per cent., and the mica from Abborfors in Finland contains, according to Svanberg, 35·78 per cent. ‡

When the alkaline silicates of felspar are partially decomposed

* See ante, p. 75.

† Edinb. Journ. of Science, iii, 61

‡ Loc. cit.

by carbonic acid the silica remains, the bases are removed as carbonates while another portion of the silicates remains unaltered and the remainder serves for the formation of mica. In the case a mixture of mica and quartz in a micaceous schist is interpreted as that the formation of the rock from one substance, felspar, or like clay-slate, a felspathic matrix may be easily understood. In fact the mica in micaceous schist is generally mixed mica, which contains not little magnesia; and the more-magnesian pseudomorphous mica is of this kind.

The elimination of silica, with the loss of quartz in the alteration of felspar has already been proved by the pseudomorphs from St. Just and Fimber.* It is probable, therefore, that the considerable amount of silica in II is likewise owing to elimination of silica. Since the altered rhodochrosite I contains a smaller amount of alumina than any other, it may be conjectured that this earth was transferred from one portion of the felspar to another, and that such an accumulation contributed to the conversion of the felspar into mica.

The pseudomorphs of St. Just and Fimber, as well as those represented by II* and III, would appear, therefore, to be substances analogous to micaceous schist, which have originated from felspar by alteration, a portion of the alkaline silicates having been eliminated, another portion decomposed by carbonic acid, the bases removed, and the silica left in the state of quartz. However, the pseudomorphs from Lönseitz† which do not contain any quartz, show that the alteration may take place in such a way that the whole of the silica of the decomposed alkaline silicates is removed. The mica that has originated by this alteration has a perfectly normal composition, agreeing with that of the mica represented by V, VI, and VII. This correspondence is so great that the possible formation of these minerals from felspar cannot be questioned.

When mica originates from amorphous felspar it presents its proper crystal form, and such an origin cannot be traced mineralogically. The mica in granite may, therefore, have originated from amorphous felspar, the silica of the decomposed alkaline silicates having either been entirely removed, or remained in the state of

* See ante, pp. 172 and 173.

† Blum did not find any quartz mixed with the mica of this pseudomorph—see ante, p. 173—and for that reason I stated that the eliminated silica had been removed. However, the analysis II. shows that there was some uncombined silica present, though so intimately mixed with the mica as not to be recognizable.

‡ See ante, p. 172.

quartz. In the latter case the quartz in the granite would have originated in this manner.

With regard to the above-mentioned formation of double silicates of alumina and iron, from silicate of alumina and peroxide of iron, it may be remarked that if this alteration is accompanied by a partial elimination of a basic double silicate, it is possible to understand how the double silicates formed in this manner may sometimes contain excess of alumina, and sometimes excess of peroxide of iron. When very ferruginous water comes in contact with felspar a considerable amount of basic double silicate may be removed from the double silicate formed, and, in this way, much alumina would be eliminated, while peroxide of iron was substituted for it. But if the water does not contain much iron, but little basic silicate would be formed, little alumina would be eliminated, and little peroxide of iron introduced.

It is certain that the very great variation of the amounts of alumina and peroxide of iron in the mica originating from felspar, is not owing to variation in the amounts of these substances in felspar, for the amount of iron in this mineral is always very small, and that of alumina very nearly uniform. There is no doubt, therefore, that in all cases where a mineral of nearly uniform composition undergoes conversion into another mineral whose composition is variable, the chemical diversity of the substances which are mineralogically identical, is altogether owing to the qualitative and quantitative relations of the substances dissolved in the water by which the alteration is effected.

It has long been known that alumina and peroxide of iron are isomorphous and may replace each other, so that, according to the amount of these substances in the material from which a mineral is formed, the one or other base may predominate. It may, therefore, be inferred that this isomorphous relation of these bases would be of some influence, when minerals containing silicates of alumina are subjected to the action of ferruginous water. It has already been pointed out that the results of such an action may be supposed to vary; and I believe that it will furnish a clue to the elucidation of similar phenomena of mineral alteration.

The mineral previously mentioned* as resembling pinite with the form of labrador, with micaceous scales, shows that labrador, like orthoclase, is susceptible of conversion into mica. Its occurrence in decomposed basalt, a labrador rock,† is, therefore, easy to

* See ante, p. 277.

† See ante, p. 386.

be accounted for. But since the mica originating from labrador will probably never be magnesia mica, the material for the formation of magnesian mica occurring in decomposed basalt must have been furnished by labrador and augite conjointly; the latter furnishing the magnesia chiefly.

There is no evidence by which to determine whether other kinds of felspar are susceptible of conversion into mica. It is, however, very probable that they are; and it is much to be desired that attention should be directed to this question.

*Mica, with the form of andalusite.**

	I.	II.	III.	IV.
Silica	59·01	....	44·71	36·74
Alumina	26·56	} 35·33	35·29	59·66
Peroxide of iron	6·63		4·12	2·80
Lime ....	....	....	0·98	0·49
Magnesia	3·64	0·15	0·39	....
Alkalies	4·16†	....	8·82‡	....
Loss by ignition ....	....	2·40	5·69	....
	100·00		100·00	99·68

I and II. Pseudomorphous mica.

The quantity of material was too small for a complete analysis; so that I restricted myself to determining whether it was potash or magnesian mica.

III. Altered andalusite crystals, from Lisens. Roth.§

This mineral presented large laminæ of white mica at the surface and interior; and, at other parts, was entirely converted into cyanite.

If the conversion of andalusite into the mica, represented by III, consisted in the elimination of so much alumina, as the former mineral contains more than the latter, and the introduction of peroxide of iron, magnesia and alkalies, the volume of the andalusite must have been reduced 10 per cent. However, an andalusite crystal in Blum's collection is so completely filled with mica, that such a reduction of volume cannot have taken place. There may have been a partial displacement of alumina by oxide of iron.|| Comparison of the composition of the mineral repre-

* See ante, p. 271.
† And deficiency.
‡ Estimated by deficiency.
§ Zeitschrift der deutschen geol. Gesellschaft.
|| See ante, p. 74, No. 49.

sented by III, with that of the andalusite from Lisenz,* shows that there is an increase of 4·6 per cent. in the amount of silica, which is to be ascribed to the introduction of alkaline silicates. The alteration of andalusite would, therefore, appear to consist in the introduction of peroxide of iron and alkaline silicates; and the elimination of a portion of the alumina as silicate.

As the conversion of andalusite into mica is attended with a diminution of the amount of alumina, and increase of the amount of silica, while in the conversion of andalusite into cyanite, the reverse takes place, it is possible that these opposite changes may have compensated each other, if, as is probable, these two alterations went on together in the mineral represented by III. In that case, the andalusite would have been converted into mica, containing a smaller amount of alumina, and into cyanite, containing a larger amount of alumina. The very large amount of iron in IV shows, that besides this, peroxide of iron must be introduced in the conversion of andalusite into cyanite. Perhaps the mica with the form of cyanite, previously mentioned,† may have originated from andalusite, together with the cyanite.

Mica, with the form of tourmaline. ‡

				I.	II.	III.
				Tourmaline.	Mica.	
Specific gravity	....	....	....	3·055	2·831	...
Silica	....	....	....	36·70	48·78	...
Alumina	....	....	....	35·35	32·36	36·33
Peroxide of iron	....	....	...	11·25	3·06	
Lime	....	....	....	0·75	0·29	...
Magnesia	....	....	....	4·56	1·28	1·50
Alkali	....	....	....	11·09	KO 10·25	5·87
Boracic acid	....	....	....		NaO 1·55	1·30
Fluorine	....	....	....	0·30	...	...
Loss by ignition	....	....	...		HO 2·43	...
				100·00	100·00	

I. Black tourmaline.

Rammelsberg. §

This mineral was rather soft, and not quite unaltered.

II. Silver-white mica, blended with the previous mineral.

} Rammelsberg. §

* See ante, p. 267.

† See ante, p. 272.

‡ Ibid p. 261.

§ Poggend. Annal. lxxxi, 38.

This mineral had, undoubtedly, originated from the tourmaline.

III. Ochre-brown mica, with the form of tourmaline.

The tourmaline crystal was decomposed throughout, and had a dark, ochre-brown colour. The mica was situated not only on the surface, but also upon the surfaces of fracture, as very small laminae. As the quantity of material was not sufficient for a complete analysis, I restricted myself to the estimation of the bases only. Boiling hydrochloric acid extracted from this mica 1.51 per cent. alumina and peroxide of iron, with traces of lime and magnesia; the mica, at the same time, became silver-white. After forty-eight hours' digestion with sulphuric acid, 1.23 per cent. alumina and peroxide of iron, with 1.5 per cent. magnesia, were extracted. This mica is not readily decomposed, even by hydrofluoric acid. It is deserving of notice, that peroxide of iron is extracted together with alumina; for in the conversion of tourmaline into mica, both bases would be partially extracted. The nearly equal quantities of alumina, peroxide of iron and magnesia in II and III, show, that, in both instances, the alteration has been of the same kind.

Rammelsberg* found that the red tourmaline of Rozena, in Moravia, was partly opaque, with little lustre, not very hard, and was mixed with scales of lepidolite; the composition differed altogether from that of red tourmaline; and it was, undoubtedly, in a state of decomposition. This induced him to make an analysis of the lepidolite also.

	IV.	V.	VI.	VII.
Fluorine	2.70	7.12	7.47	8.16
Phosphoric acid ...	0.22	0.16	0.13	...
Silica	41.16	51.70	46.52	48.65
Boracic acid	8.56	...	...	...
Alumina ...	41.83	26.76	21.81	17.67
Peroxide of iron ....	...	...	4.78	...
Protoxide of iron ....	...	...	6.80	14.57
Protoxide of manganese	0.97	1.29	1.96	1.24
Lime ....	...	0.40	...	...
Magnesia	0.61	0.24	0.44	0.53
Potash	2.17	10.29	9.09	8.60
Soda	1.37	1.15	0.39	0.71
Lithia	0.41	1.27	1.27	2.41
	100.00	100.38	100.66	102.54

* Poggend. Annal. lxxxi, 17 and 39.

IV. Red tourmaline, from Rozena.

V. Lepidolite, associated with it.

VI. Lepidolite occurring as large laminæ } Rammelsberg. *

with quartz.

VII. Lepidolite, from the Zinnwald. Stein.†

Rammelsberg ‡ calculates the oxygen ratio of the strong bases, the weak bases, and the silica in the mica of Zsidovacz, in Hungary, from the analysis by Kussin, as = 1 : 9 : 12, and the oxygen quotient as 0·833; in the mica of Utö, Broddbo, Fahlun, Kimito and Ochotzk, he calculated the oxygen ratio, from the analyses by H. Rose, as 1 : 12 : 15, and the oxygen quotient as 0·866. Consequently, the composition of the former mica is analogous to that of the tourmaline included in group IV, and the composition of the latter mica is analogous to that of the tourmaline included in the group V. §

In the tourmaline analyzed by Rammelsberg, soda always preponderates over potash. In the brown and black kinds, the maximum amount of soda is 2·6 per cent.; that of potash 0·73 per cent.; and that of lithia 1·47 per cent.; the maximum amount of the three alkalies being 4·52 per cent. Consequently, the conversion of tourmaline into mica involves displacement of soda by potash, by means of the reaction between silicate of soda and carbonate of potash. || But as the amount of potash present in most varieties of potash mica would not be attained in this way, a further quantity of potash must be introduced otherwise.

The largest amount of lime in the above-mentioned mica is 1·81 per cent.; but it is generally under 1· per cent. By the reaction of the silicate of lime with carbonate of potash, ¶ a further quantity of this alkali would be introduced.

Comparison of II and I shows that the boracic acid has been entirely eliminated, the peroxide of iron and magnesia for the most part, and alumina partially. This must have produced a relative increase of the amount of the other constituents; but as the amount of silica has been considerably increased, a relative increase of the amount of alkaline silicates would not account for the considerable amount of alkalies in the mineral represented by II. The diminution of specific gravity, in consequence of the

* Poggend. Annal. lxxxi, 44,

† Polytechn. Centralblatt. 1847, No. 23.

‡ Loc. cit.

§ See ante, p. 258.

|| See ante, p. 65, No. 38.

¶ English edition, i, 8.

conversion of the tourmaline represented by I into the mica represented by II, shows that 7·33 per cent. of the constituents of the former may be eliminated without reduction of the volume.

It follows from these considerations that the process of alteration in this case is still involved in obscurity; a much greater number of analyses must be made before it can be satisfactorily accounted for.

The constant association of mica and hydrated peroxide of iron upon altered tourmaline, has already been mentioned.* The pseudomorphous mica represented by III, is covered by an incrustation of peroxide of iron. If ferruginous tourmaline is converted into potash mica, there must be an elimination of iron. Dark-colored mica is also mentioned as occurring at the above-mentioned place, and has undoubtedly originated from tourmaline; whether or not it is ferruginous magnesian mica must be determined by analysis. In the formation of mica of this kind the alteration would be different.

Comparison of the composition of the red tourmaline represented by IV, with that of the lepidolite represented by V, VI, and VII, shows that in the conversion of one into the other boracic acid is entirely eliminated, the alumina to a considerable extent, while fluorine and alkalies are introduced. In the formation of the minerals represented by VI and VII, a quantity of magnetic oxide of iron is introduced, which may be owing to displacement of alumina by oxide of iron.† In other respects, the remarks made in reference to the conversion of black tourmaline into mica are applicable here also.

In the mineral represented by IV, the amount of potash is greater than that of soda, while in all other kinds of tourmaline the reverse proportion obtains; therefore Rammelsberg's conjecture that this mineral is already altered, is, to some extent, confirmed. This alteration must, therefore, have consisted in a substitution of potash for soda, and is rather far advanced.

* See ante, p. 264.

† See ante, p. 74, No. 49.

Mica with the form of wernerite.*

	I.	II.	III.	IV.	V.	VI.
Silica	65.82†	46.75	42.59	44.49	52.63	49.5
Alumina	27.37	26.15	21.68	24.91	29.46	27.5
Peroxide of iron			10.39	4.84	5.72	....
Oxide of manganese ....	....	....	0.75	....	....	....
Lime ....	....	....	0.26	2.14	2.52	15.0
Magnesia	0.42	15.78	10.27	0.36	0.43	....
Potash	5.77	5.64	8.45	6.71	7.94	....
Soda	0.42	0.82	....	1.11	1.30	8.0
Fluoride of calcium ....	....	....	1.07	....	....	....
Carbonate of lime ....	....	....	....	11.11	....	....
Water	0.20	0.63	3.35	3.44	....	....
Loss ....	....	4.23	....	....	....	....
	100.00	100.00	98.81	99.11	100.00	100.00

I. Mica, with the form of wernerite, from Arendal.

II. Mica, with the form of wernerite, from Pargas; both analyzed by myself.

The latter mineral was completely decomposed by sulphuric acid. The large deficiency is a consequence of my being able to use only a very small quantity for analysis.‡

Both specimens of mica were greenish-white, and the lustre was not affected by ignition, although they became silver-white.

A specimen of calc-spar blended with wernerite, from Pargas, contained at one part a small plate of mica, and was only partially dissolved by hydrochloric acid. The residue appeared to be wernerite, with a few laminæ of mica. The wernerite contained traces of magnesia.

III. Mica from Pargas. Svanberg.

This is the only analysis of mica from this locality.

IV. Greenish-white, perfectly transparent mica, with the form of wernerite, } G. v. Rath.§
from Arendal.

The surfaces of the crystals were covered, and their interior filled with laminæ of mica. Between the laminæ were quartz, small

* See ante, p. 240.
† Estimated from the deficiency.
‡ The mineral was previously digested with hydrochloric acid, which extracted alumina, much lime, and a trace of magnesia.
§ Poggend. Annal. xc, 288, et seq.—The difference between this analysis and I, is partly owing to the circumstance that the mica had been previously digested with hydrochloric and sulphuric acid, so as to extract carbonate of lime and other extraneous substances. Hydrochloric acid extracted ferruginous alumina, much lime, and some magnesia; sulphuric acid extracted 3.19 per cent. ferruginous

crystals of iron pyrites, and sometimes a soft green substance, with scarcely any cleavage, which was, apparently, an intermediate product of the alteration. Carbonate of lime was not recognizable by the eye, and there was not any fluorine in the mineral.

V. The same mica, after deducting water and carbonate of lime.

VI. Normal composition of wernerite.

It follows from the above analyses that wernerite is susceptible of conversion into potash mica as well as magnesian mica.

A comparison of I with the analysis of decomposed wernerite,* shows an unmistakable similarity, and it is, therefore, probable that this wernerite is in some stage of conversion into mica. If the residual silicate of lime had been converted by means of carbonate of potash into silicate of potash,† it is probable that mica would have been formed.

Attention is directed by v. Rath to the circumstance that the proportion of silica to alumina is the same in V and VI; that in the place of soda, there is in VI, an equal amount of potash, and the excess of soda in V, shows that the original mineral lost 12·48 per cent., while only 5·72 per cent. was introduced into the product of alteration. But since the latter has the greater specific gravity, the crystallization of the mica must have been attended with a reduction of volume. The introduction of peroxide of iron he supposes to have been effected by the oxidation of bicarbonate of iron in water, and the decomposition of silicate of lime by the carbonic acid, so that bicarbonate of lime was formed and removed while silicate of iron took the place of the silicate of lime.

It has already been shown that hydrated peroxide of iron decomposes silicate of lime, a double silicate of lime and iron being formed.‡ It may, therefore, be supposed that the carbonic acid liberated from the bicarbonate of iron would combine with the lime of the double silicate and remove it as bicarbonate, leaving silicate of iron. The conversion of the silicate of soda in wernerite, into the silicate of potash in mica would be effected by the reaction with carbonate of potash.§

alumina, and 0·42 per cent. lime. As the quantity of material at my disposal was very small, I restricted myself to ascertaining whether the mineral was magnesian or potash-mica. v. Rath's analysis is most likely more accurate than mine, as he had a larger quantity of the mineral; but both analysis agree in showing that this mica, with the form of wernerite, is potash mica.

* See ante, p. 247, No. I.

† English edition, i, 8.

‡ See ante, p. 77, No. 50.

§ See ante, p. 65, No. 38.

There is a certain degree of resemblance between II and III, which is remarkable since the corresponding specimens of mica occur at the same place, and are both magnesian mica. The conversion of wernerite into magnesian mica would be effected by water, containing, besides carbonate of potash, bicarbonate of magnesia.*

The conversion of wernerite into potash mica would be effected by the action of water containing carbonate of potash and bicarbonate of iron. If the water contained carbonate of magnesia also, the silicate of lime would be decomposed, silicate of magnesia and carbonate of lime formed, the latter being removed by water, and the former introduced into the mineral. In this decomposition there may be a partition of the silica between the peroxide of iron and alumina and a double silicate formed.†

Conversion of beryl into mica and quartz.—Blum ‡ found in a coarse grained granite at Heidelberg, small crystals of beryl, generally in an altered state, and sometimes entirely converted into a mixture of mica and quartz, retaining the original form. The mica laminæ were greenish or reddish, and covered with a ferruginous crust. One crystal was unaltered at one end while at the other end it consisted entirely of mica and quartz. The beryl crystals from Bavaria sometimes present indications of an incipient conversion into mica. One specimen contains a great number of mica laminæ, and at many places is covered with mica. The beryl from Royalstone, in Massachusetts, also contains mica where it is turbid. Even emerald from Siberia generally presents a transition into mica at the ends of the crystals; by the aid of the magnifying glass a mixture of mica and emerald is easily recognized. G. Rose informs me that Berzelius in his description and examination of the minerals of Finbo, near Fahlun, mentions, under the name pseudo-emerald, beryl crystals several inches long, that were entirely converted into mica. G. Rose saw them in 1821, at Stockholm.

The following analyses by H. Müller,§ throw some light upon this alteration.

* English edition, i, 13, No. 16.

† See ante. p. 75.

‡ Nachtrag, 2, p. 42.

§ Korrespondenz-Blatt des zoologischen-mineralogischen Vereins in Regensburg, 1852, p. 70.

	I.	II.	III.	IV.
Silica	67.0	67.4	58.8	66.90
Alumina	19.8	20.0	54.7	18.45
Glucina	13.2	12.0	10.2	12.20
Peroxide of iron ...	0.8	0.3	2.6	2.95
Water ....	....	...	2.5	....
	100.8	99.7	98.8	

I. Beryl from the pegmatite of Sägemühle, south of the Fichtelgebirge.

II. Beryl from Schwarzenbach, in the same neighbourhood.

III. Décomposed beryl from Sägemühle.

IV. Beryl from Heidelberg, analyzed by Bornträger.*

This corresponds very closely with I and II.

The decomposition of beryl appears, therefore, to consist essentially in elimination of silicate of glucina and of silica.† Its conversion into mica requires, besides this, introduction of alkaline silicates. As glucina is dissolved by alkaline bicarbonates, and as these are products of the decomposition of felspar in granitic rocks, the removal of the glucina may be accounted for. The masses of beryl from the pegmatite are traversed by fissures partly filled with quartz. They are frequently mixed with felspar containing isolated laminæ of mica. Blum remarks that the beryl substance has sometimes wholly disappeared, so that there is either a cavity or only a porous aggregate of quartz granules or crystals. It is probable, that in this case, the potash requisite for the formation of mica was wanting.

ALTERATION OF MICA.

Conversion of magnesian mica into potash mica.—I have already remarked ‡ that on treating mica, originating from Fahlunite, with sulphuric acid, white, silvery laminæ remained, and that this is also the case with several specimens of micaceous schist from the Zillerthal, and from Libethen in Hungary. Analyses gave the following results.

* Jahrbuch für Mineral, etc. 1851, p. 185.

† When beryl is entirely decomposed, kaolin remains ; see ante, p. 177.

‡ See ante, p. 280.

1. Sulphuric acid extracted larger amounts of bases the greater the amount of magnesia.

2. Alumina, protoxide of iron and magnesia, were always extracted by sulphuric acid in much greater amount than alkalies; so that the alkaline silicates are not so readily decomposed by this acid as the silicates of those bases.

The fact that pure potash mica is not at all acted upon by sulphuric acid, and is with difficulty decomposed by hydrofluoric acid, agrees with this latter result. Consequently, the slight tendency of mica to decomposition is not owing to the presence of silicate of magnesia;* but, on the contrary, mica is more readily decomposed the greater the amount of this silicate, while pure potash mica is least of all susceptible of decomposition.

It is, therefore, easy to suppose magnesian mica may be converted into potash mica. Such an alteration would appear to be the result of the action of atmospheric constituents upon magnesian mica.† The more easily decomposable magnesian mica is converted into potash-mica. But when the substances eliminated, accumulate at some places, it is possible, that, by the introduction of silicates of magnesia and protoxide of iron, potash-mica may be converted into magnesian mica; for this latter may be regarded as a compound of potash-mica with these silicates. However, both kinds of mica may be simultaneously produced from one mineral, and thus become blended in the manner that they are found to occur.‡

Conversion of mica into steatite. § The alteration commences at the lateral faces, and extends along the planes of cleavage. || Daub ¶ found the mica in felspathic porphyry, converted into a yellowish-green mass, probably steatite; particles of the mica laminæ could still be recognized in it.**

C. G. Gmelin †† directs attention to the gradual transition of mica into talc, also recognizable in the transition of micaceous schist into talcose schist.

Conversion of mica into serpentine.—At Sommerville, mica occurs which has been converted into serpentine.‡‡ The remarks

* See ante, p. 367.

† See ante, p. 366.

‡ German edition, ii, 1389.

§ See ante, Chapter xx, p. 14.

|| Blum.—Nachtrag, p. 73 et seq.

¶ Jahrbuch für Mineral. etc. 1851, p. 4.

** Chapter xli.

†† Poggend. Annal. vi, 226.—Rammelsberg's Handwörterbuch, Suppl. 2 p. 144.

‡‡ Blum.—Nachtrag, p. 79 et seq.

already made respecting the conversion of mica into steatite, are also applicable to this alteration. These pseudomorphs also occur associated with calc-spar and unaltered mica.

Serpentine, steatite, and talc, which are so closely related to mica, and appear only as products of the alteration of other minerals, may, therefore, originate from mica.

There is only one instance known of the displacement of mica by another mineral, hornstone ; * and, so long as there are no other instances observed, it would be premature to offer any remarks upon this phenomenon.

CHAPTER XXXIX.

CHLORITE.

THIS mineral is decomposed by concentrated sulphuric acid. It is somewhat considerably acted upon by hydrochloric acid after ignition, but not before.

Occurrence.—In chloritic schist, a rock that is not very frequent ; in fissures, drusy cavities, and metalliferous lodes. It often occurs as an incrustation of rock crystal, calc-spar, felspar, axinite, titanite, pericline, etc. It appears to have a tendency to association with other minerals, communicating to them a green colour. Even the green colour of rocks, such as diabase, † is owing to the presence of chlorite.

Composition.—The essential constituents of chlorite, are silicates of alumina, protoxide and peroxide of iron, magnesia, and water. It does not contain silicate of lime. Sometimes it contains a minute amount of chromium.

Rammelsberg ‡ endeavoured to estimate the relative amounts of protoxide and peroxide of iron in the varieties of chlorite, so as to arrive at some more definite notion of the constitution. The oxygen ratio of chlorite and ripidolite is calculated from his results, and the analyses of chlorite, by Brüel, v. Kobell, and Varrentrapp, as well as that of ripidolite by Varrentrapp, are corrected in accordance with them.

* See Chapter xlii.

† Volger.—Studien zur Entwicklungsgeschichte der Mineralien, p. 83.

‡ Suppl. 4, p. 34.

		Chlorite.					Ripidolite
		<i>Schwarzenstein.</i>	<i>Achmatowsk.</i>				<i>St. Gotthard</i>
		Brüel.	v. Kobell.	Varrentr.	IV.	V.	Varrentr.
Silica	....	31.47	31.47	30.38	30.01	31.34	25.37
Alumina	....	16.67	17.14	16.97	19.11	17.47	18.50
Peroxide of iron	....	3.36	....	....	4.81	3.85	13.22
Protoxide of iron	....	2.95	4.55	4.55	....	....	16.89
Protoxide of manganese	....	0.01	0.53	....	....	1.69	....
Magnesia	....	32.56	34.40	33.97	33.15	33.44	17.09
Water	....	12.43	12.12	12.63	12.52	12.60	8.96
		99.45	99.88	98.50	99.60	100.39	100.03

Other analyses of ripidolite have already been quoted.*

- IV. Crystallized chlorite—vermicular chlorite†
—from the Ala valley
- V. Clinocllore, a mineral from West-Chester,
Pennsylvania
- Analyzed by
Marignac.‡
Blake.§

This mineral resembles mica, but chemically, it is unquestionably analogous to chlorite.

The variation in these analyses may be owing, in part, to the presence of adventitious substance deposited by water, which by reason of the extreme divisibility of chlorite, penetrates very readily. But, for the same reason chlorite is the more liable to chemical alteration.

Chlorite with the forms of other minerals.—The conversion of hornblende|| and garnet¶ into chlorite, with simultaneous elimination

* See ante, p. 250. † Volger calls this mineral helminthe.
‡ Ann. de chim. et phys. Sér. 3, x, 430.
§ Amer. Journ. of Science, xii, 339, and xii, 222. || See ante, p. 346.

¶ See ante, p. 290.—In the Berlin mineral collection I found several specimens of garnet, from the micaceous schist of the Tyrol, completely covered with chlorite. The incrustation of chlorite passes suddenly into garnet. In one instance there was iron pyrites also upon the garnet. A specimen of garnet from Fahlun presented a very thin incrustation of chlorite. A specimen of dark green chlorite, from the serpentine of the Col. de Pertuis, in the Vosges, was analyzed by Delesse.—Ann. des Mines. Sér. 4, xviii. 321.—It contained some garnet, from which it appeared to have originated, and consisted of

Silica	....	....	....	33.23
Alumina	....	....	....	14.78
Oxide of chrome	....	....	....	1.49
Peroxide of iron	....	....	....	6.28
Protoxide of manganese	....	....	....	1.39
Magnesia	....	....	....	30.76
Lime	....	....	....	1.86
Water	....	....	....	10.21
				100.00

The composition of this mineral corresponds, therefore, with that of the

of lime, proves the possibility of its formation from other minerals containing silicate of lime. Moreover, minerals containing alkaline silicates like tourmaline,* are susceptible of conversion into chlorite. As felspar† may also be converted into chlorite, it may be understood why chloritic minerals occur in most rocks like clay-slate.

The chlorite pseudomorphs formed by displacement are especially important.

Chlorite with the form of fluor-spar.—This pseudomorph occurs at Berggieshübel in Saxony. It is described by Blum.‡ Sometimes the pseudomorph contains a nucleus of fluor-spar, sometimes it consists entirely of chlorite. In the octahedral forms the alteration may be very distinctly traced; they are either covered with a crust of chlorite, or present patches of chlorite, extending more or less into the mass of the crystal, generally in the direction of the cleavage planes. In a similar manner chlorite penetrates between the particles of granular aggregates of fluor-spar, forming a perfect mixture of the two minerals. Sometimes the direction of the cleavage planes of fluor-spar may be traced, notwithstanding the admixture of chlorite.

Chlorite with the form of calc-spar.—The pseudomorph occurs at Büchenberg near Elbingerode in the Harz mountains, according to Sillem.§ The rhombohedral masses sometimes contain a nucleus of calc-spar, and are sometimes hollow. In some instances there are laminæ of chlorite in the direction of the cleavage planes of the calc-spar. The chlorite is laminar, blackish-green, and generally incrustated with hydrated peroxide of iron.

Volger|| describes a series of 28 specimens of this pseudomorph presenting different phases of alteration. It occurs in druses, but generally filling fissures. The calc-spar mass is distinctly separate from both surfaces of the fissures, and there are saalbands of chlorite, generally very thin. At the saalbands of one specimen, fragments of calc-spar, that had been covered with a crust of chlorite, have been subsequently removed, leaving angular, hollow spaces, in which there is some iron-ochre. Where the chlorite substance has entirely penetrated the calc-spar, the mass has an intense green, the cleavage of calc-spar is no longer distinct, and

chlorite above mentioned. The presence of lime favours the opinion that it originated from garnet.

* See ante, p. 263.

† See ante, p. 173.

‡ Nachtrag, 2, p. 104.

§ Jahrb. für Mineral. etc., 1851, p. 395.

|| Loc. cit. p. 89.

the fracture appears compact and earthy. In several instances the spaces formerly containing calc-spar, contain earthy chlorite.

Volger questions the existence of the displacement of pseudomorphs of chlorite after brown iron-ore, described by Sillem.

Chlorite with the form of magnetic iron ore.—Sillem* states that this pseudomorph also occurs at Büchenberg. He considers that the magnetic iron-ore crystals, covered with chlorite, from Fahlun, are of the same kind, but only in an early stage of production. Blum† however, found, in one instance, that the magnetic iron-ore was completely displaced. When a nucleus of magnetic iron-ore remains, its surface is rough and uneven; sometimes the chlorite extends far into the mass of the nucleus. Blum states that similar pseudomorphs occur at Berggieshübel.

Volger‡ has pointed out some interesting facts illustrative of the tendency of chlorite to association with other minerals. In one specimen, from the Kreuzli valley in Graubünden, situated upon a rock that he calls chloritic gneiss, the calc-spar upon one-half of the faces was of a form different to that on the other half of the faces. Between the calc-spar crystals and the rock were a few adular crystals. The whole surface is covered with scaly chlorite as a delicate film; but between the calc-spar rhombohedrons, it forms thick layers from which only a few portions of the crystals project. The chlorite frequently appears as a thin compact crust upon some of the crystal faces of both kinds of the calc-spar crystals, and also upon those of adular.

The scalenohedrons of calc-spar that are most remote from the rhombohedrons are partly colorless, at some places colored green by intruded chlorite, and the colour becomes more general nearer to the rhombohedrons. The crystal faces, however, appear clean and lustrous; it is only by the aid of the magnifying glass that they are found to be corroded and covered with innumerable holes, filled with scales of chlorite.

On the contrary, the faces of rhombohedral crystals, are, with few exceptions dull, slightly drusy and green colored. The chlorite laminæ are not situated upon the faces of the calc-spar crystals, but evidently extend into the masses of the crystals in the direction of the cleavage.

Similar characters are presented by the scalenohedrons, some of which are quite leek-green; but the chlorite in this case does

* Loc. cit. pp. 396 and 400.

† Nachtrag, 2, p. 106.

‡ Loc. cit. p. 116.

not extend into the mass from the faces of the crystals, but at the irregular parts where the crystals are attached to the rock. But still the direction in which the chlorite extends into the calc-spar is so closely correspondent with that of the cleavage planes, that even in the scalenohedrons an inner rhombohedral form is thereby recognizable. Some of these crystals which at first sight appear quite leek-green, prove, upon closer examination, to be colorless at parts, and at others only slightly tinged through, while the rhombohedron within is intensely green at some of the faces. In one instance, the three rhombohedral faces of one-half of a crystal, which are turned towards the part where the rhombohedrons of calc-spar are situated, are much corroded and covered with chlorite, while the scalenohedral faces of the other half of the crystals are bright and clean. The supplementary faces of the rhombohedron are recognizable at the interior by the way in which chlorite extends into the mass. Wherever scalenohedral faces, however small, appear upon the rhombohedrons, those faces are bright, and quite free from chlorite.

Consequently, it would appear, that the rhombohedral crystals presented a less obstacle than the scalenohedrons to the penetration of the liquid from which chlorite was deposited.

The edges of the rhombohedrons, whose faces are covered with chlorite, appear rounded, corroded, and also free from chlorite at these parts, so that this corrosion does not appear to be a consequence of the formation of chlorite, but to have taken place subsequently. However, most of the rhombohedrons are much more strikingly corroded, all that remains of them being a very thin shell underneath the covering of chlorite. In many instances, one or other face of the rhombohedral crystals, and also an edge or corner, is pierced as if with a needle. The least touch with a knife breaks the delicate shell, and upon the sides of the hollow there is found a blackish-brown dust containing manganese. In one instance the inner surface of such a shell was found to be covered with chlorite, and sometimes they contained rhombohedral fragments of calc-spar.

Volger* describes a calc-spar druse upon which there are small quartz crystals. It is partly covered with very minute laminæ of chlorite, which is so abundant at the angles which the crystals form with each other, and between the quartz crystals, that they appear as if imbedded in chlorite. The chlorite is of the kind which Volger calls *helminthe*; it appears to have penetrated into

* Loc. cit. p. 131.

all the calc-spar crystals, and has colored them to the depth of a quarter of a line. The quartz crystals are dull and rough at all their faces, and chlorite extends into their mass to the depth of $\frac{1}{8}$ of a line.

In the pseudomorphs of chlorite after calc-spar, as well as in those previously mentioned, the chlorite is more recent than the calc-spar into which it has penetrated.

Blum * mentions the occurrence of a chloritic substance as a petrifying material in the clay-stones of the old red sandstone, near Zwickau in Saxony, where remains of *neuropteris grangeri* consist entirely of this green chloritic substance. Volger † also found, in a sandstone, near Zurich, fossils which formerly consisted of calc-spar, but in which the carbonate of lime had been wholly or partially displaced by earthy chlorite.

A large crystal of white adular from St. Gotthard, enclosed within it calc-spar, containing ogkoite‡ and carbonate of iron. The calc-spar is almost everywhere surrounded by ogkoite, and at many parts, is displaced by it. Volger § considers it unquestionable that the ogkoite existed previous to the formation of the adular. Innumerable small crystals of adular were formed upon the ogkoite, chiefly in the depressions between the plates and nodules. As these crystals increased in size they would eventually form one large crystal. A great number of isolated crystals are still attached to the ogkoite; others are attached by one face to the large adular crystal. The calc-spar is obviously older than the ogkoite, and in some instances its subsequent removal may be recognized.

The above-mentioned pseudomorphs of chlorite with the form of calc-spar do not present very striking indications of such displacement. The carbonate of lime does not appear to have been removed to any great distance, for between the plates of ogkoite at the side of the specimen opposite to that where the adular is situated, there are a number of small white calc-spar crystals frequently associated with small adular crystals. The calc-spar crystals are quite fresh and clear, and very different from the partially destroyed calc-spar resembling ankerite. The carbonates of lime in the latter mineral would be separated as hydrated peroxide of iron.

Very thin six-sided plates of silver-white mica also occur as

* Nachtrag, 2, p. 126.

† Loc. cit. p. 134.

‡ A variety of chlorite.

§ Loc. cit. p. 146.

isolated patches upon the ogkoite and adular, so that it is more recent than either.

The large adular crystal contains, here and there, very minute needles of rutile; at one part they are woven into a kind of net. Titanite crystals that are barely recognizable, are situated in great numbers upon the faces of the adular crystal, and between the laminar ogkoite, together with calc-spar and small crystals of adular. Near the net of rutile needles, Volger found a small crystal of helminthe, which is quite distinct from ogkoite.

The sequence of formation in this specimen is:—1 calc-spar; 2 rutile, ogkoite; 3 adular; 4 mica, titanite, calc-spar, and helminthe.

Volger* describes another specimen of a felspathic rock that is no less interesting. One surface, and one side of its edge is covered with fine nodules of ogkoite. It consists of a large number of very small adular crystals, loosely aggregated, so that there are a great number of angular interstices. In these spaces there is a tissue of very delicate needles of rutile with adherent traces of iron ochre. The whole of the rock presents impressions of long bunches of actinote; but there are no remains of the mineral itself. The spaces from which it has been removed, contain iron ochre, and the same kind of ogkoite as that in the last-mentioned rock.

In this instance, therefore, ogkoite appears to be epigenetic, perhaps it is pseudomorphic after actinote, by displacement. Volger is also convinced that the adular was not formed until after the actinote had been removed. He considers that the only assumption possible, is that an entirely different mass formerly occupied the place of this rock. In this mass the actinote was imbedded, subsequently decomposed and removed, ogkoite being deposited in its place. But the matrix was also decomposed, and during this alteration the granular adular mass was substituted, while adular crystals extended between the ogkoite laminæ and into the cavities left by the actinote.

The sequence of formation in this specimen is represented by Volger as:—1 actinote, rutile,—perhaps the only remnant of the original rock;— 2 ogkoite; 3 adular.

Subsequently Volger† found in the mineral collection at Zurich, a rock which resembles that above described, so completely that it may be supposed to originate from the same locality. How-

* Loc. cit. p. 153.

† Loc. cit. p. 546.

ever, it consists, not of pure granular felspar, but principally of a compact limestone resembling ankerite.

Examination of another specimen showed that the titanite crystals covered the faces of a calc-spar crystal; further that the titanite was surrounded by adular, and that the calc-spar was removed. At the other side of the rock, all the adular crystals were so covered with helminthe, that they could only be recognized by the form; the helminthe also extended into the mass of the adular crystals. When titanite projects beyond the adular, its surface is covered with helminthe, which also extends into the mass. Generally the titanite is somewhat more free from this incrustation.

With regard to the occurrence of helminthe in and upon quartz crystals Volger* states that a group of these crystals from St. Gotthard, is unequally covered with helminthe; at some parts the incrustation is so thick that the quartz cannot be seen, and here the ends of the crystals are so entirely wanting that there remains only a portion of one pyramidal face; all the rest appears to have been abstracted. In one instance, the entire pyramid of a thick crystal has disappeared, and the prism faces are deeply corroded near the end of the crystal. Masses of helminthe are imbedded in the quartz mass, sometimes near the surface, sometimes deeper, and sometimes projecting.

In another specimen, there are innumerable thread like prisms of helminthe isolated and interwoven. When the direction of the pyramidal faces of the crystal is recognizable, it is found that the distribution of the helminthe corresponds with it. There are also plates of specular iron-ore in the same direction as the helminthe.

Volger is of opinion that the helminthe cannot have been deposited periodically, during the growth of the quartz crystals, and thus have been imbedded in the quartz; for he was unable to find a single helminthe crystal which coincided throughout its entire length, with one of the former surfaces of the quartz crystal. Generally the helminthe crystals extend both into the older and newer quartz on each side.

Volger's accurate description of the occurrence of helminthe in quartz crystals, appears to render it possible for those who have not made such observations to form an opinion; but when the phenomenon is so complicated as in the above instances this is somewhat difficult. The great compactness and imperfect cleavage

* Loc. cit. p. 165.

of rock crystal are not inconsistent with the notion of water penetrating into it; for it will subsequently be shown that proto-silicate of iron in quartz is decomposed with production of hydrated peroxide of iron. But without penetration of water, such alteration cannot be accounted for. Moreover, the artificial coloring of onyx, as practised at Oberstein proves the liquids penetrate into it.* And if liquids can penetrate into amorphous quartz, they may also penetrate into crystallized quartz more particularly since the latter has cleavage.

It seems questionable whether the position of the helminthe crystals described by Volger, proves that they were not formed during the growth of the quartz crystal. When such crystals were covered with helminthe crystals, some of which projected, and the formation of quartz was continued, the result would be that the helminthe would extend into the newer quartz. They might also extend into the older quartz if the surface of the quartz were corroded. Volger is disposed to regard helminthe as the destroyer of quartz.

In the above-mentioned groups of quartz crystals, Volger found some rhombohedrons of iron-spar, that were protected from decomposition by the surrounding quartz. These rhombhedrons, and ankerite crystals also, were covered at some parts with helminthe which also extends into the mass. If these helminthe crystals were formed after the quartz it would be remarkable that the iron-spar and ankerite, which are so susceptible of decomposition, should have been preserved. It would seem, therefore, more probable that these minerals were coated with helminthe before they were imbedded in the quartz, and that they were thus protected. But in this case the helminthe would be formed before the deposition of quartz and, as the incrustation of the quartz crystals with helminthe, shows that it was also formed after the production of quartz, it is possible that the deposition may have taken place during the growth of the quartz crystals.

Silica is present in all water that has traversed rocks for any

* Onyx is coloured black by immersion for some weeks, first in a dilute solution of honey in water, and then in sulphuric acid, which carbonizes the honey, and produces the black colour. The degree of permeability differs very much; for some specimens require to be immersed for only a few hours, while others require a day, and some are not colored at all. Chalcedony is colored citron-yellow by digesting with hydrochloric acid containing iron, which probably produces the colour. A small amount of iron extracted by the acid from the chalcedony also takes part in producing the colour.

Nöggerath.—Die Kunst Onyx zu farben.—Jahrbuch für Mineral. etc., 1847, p. 473.

distance ; but the constituents of chlorite have never been detected in water ; however, taking into consideration all the facts stated above, it seems to be a necessary inference that they are present in water, though in very much smaller amount than silica. Assuming a simultaneous, or periodic formation of quartz, and of the chlorite imbedded in it, the small quantity of the latter mineral, in proportion to the former, would furnish an indication of the amounts of the substances, from which both minerals have been formed, that are present in water.

Formation.—The situations in which chlorite is found, and its occurrence in drusy cavities and fissures, proves that it has been deposited from water ; and the conversion of various minerals into chlorite, proves that it may be produced by alteration.*

Volger, who fully agrees with me in regard to the production of pseudomorphs, and the deposition of minerals between surfaces of cleavage, remarks, that in this process it is unnecessary to suppose that there is a current of water concerned, but that the liquid has moved between the capillary interstices of the cleavage planes in the same way that a drop of water moves through a lump of sugar. However, there are cases in which the flow of water through fissures, and into drusy cavities, are concerned.

Decomposition.—Whether the chlorite which is translucent, sometimes even as thin laminæ, has lost its transparency in consequence of incipient decomposition, has not yet been ascertained ; but it is very desirable that this should be determined by means of analysis. It has already been pointed out that chlorite is one of those minerals which are least of all liable to decomposition.

CHAPTER XL.

SERPENTINE.

THIS mineral, when finely powdered, is decomposed by concentrated hydrochloric acid ; and, more completely, by sulphuric acid, the silica being separated as a powder.

Occurrence.—Serpentine occurs both as a simple mineral and as a rock. But this difference does not indicate any difference of origin ; and, consequently, the two kinds will be treated of together in this chapter.

* The formation of silicates of magnesia is treated of in Chapter XLI.

Noble serpentine occurs as veins and nests, traversing granular limestone in all directions. It also occurs in metalliferous lodes, as at Arendal, in Norway, where noble and common serpentine occur, as small patches, in magnetic iron-ore; as small veins in the adjoining rock, and as beds.*

As a rock, serpentine constitutes numerous members of the granulite formation of Saxony. Fallou states, that in this locality there are forty-eight known layers of serpentine. This formation† comprises all those kinds of serpentine that occur in the Vosges. Serpentine occurs as regular, conformable beds in gneiss, as at the Greiner, in the Tyrol, and at Snarum, in Norway, where it constitutes a lenticular mass in the gneiss. It also occurs in primitive clay-slate; in the Ural, its occurrence in this rock is very frequent. The occurrence of serpentine in granular limestone, is very remarkable. In North America, serpentine occurs very abundantly in a bed of white limestone.‡

From the association of garnet, bronzite, bastite, chlorite, mica, magnetic iron-ore, iron-pyrites, and in the Ural, platinum and chrome iron-ore, serpentine acquires the character of a mixed rock. A very homogeneous slate, from Villa-Rota, on the Po, was found by Delesse§ to have a composition so closely resembling serpentine, that it might be regarded as schistose serpentine. The only difference from serpentine is, that it contains 3·22 per cent. alumina.

Composition.—It might be expected, that a mineral, which, like serpentine, never presents any definite form, would vary much in composition. But as it is one of the final products of mineral alteration,|| and is not susceptible of any further alteration by the influence of atmospheric agents, it may easily be understood why its composition is so nearly uniform. The theoretical composition of serpentine is:—

Silica	....	....	4 eqts.	=	44·02
Magnesia	....	....	9 „	=	43·11
Water	....	....	6 „	=	12·87¶
					100·00

The results of the analyses of the purest varieties of serpentine, correspond tolerably well with the above, when it is

* Weibye.—Archiv. für Mineral. etc., xxii, 492.

† French geologists call this the “leptinite formation.”

‡ Reports of the meetings of the Assoc. of American Geologists, 1843, pp. 243 and 246.

§ Bibliothèque universelle de Genève, May 1848.

|| See ante, 113.

¶ Rammelsberg.—Suppl. 3, p. 110.

assumed, that a part of the magnesia is replaced by protoxide of iron. If the rocks from which it has been produced contained silicates of alumina, lime, etc., and the alteration is not quite complete, these earths would be found in the serpentine to some extent.

Serpentine, with the forms of other minerals.—I have already mentioned, on several occasions, that serpentine may originate from the most diverse minerals and rocks. G. Rose * agrees with me in this opinion, and adds, that serpentine is always a product of alteration.

Breithaupt† was, perhaps, the first, who, in describing the serpentine with the form of hornblende,‡ remarked, that some beds of serpentine were, perhaps, originally, hornblende or diorite. It might not be difficult, he says, to detect the conversion of one substance into the other. Some diorite beds, as, for example, those in Saxon Voigtland, acquire a fatty appearance, the mass becomes softer, less dense, and, in general, approximates to serpentine.

The conversion of augite, diallage, and bronzite into serpentine, has already been treated of. § These alterations, and those previously mentioned, as well as the conversion of garnet into serpentine,|| are, according to G. Rose,¶ illustrated in a most striking manner, by specimens in the Berlin collection of minerals. The conversion of olivine into serpentine, has already been treated of, both in its mineralogical and chemical relations.**

Conversion of chondrodite into serpentine.—The product of this alteration cannot, in the strict sense of the word, be a pseudomorph, because chondrodite very rarely presents crystalline form. The chondrodite which presents progressive conversion into serpentine, occurs in the granular limestone of Sussex County, associated with graphite; near Sparta, New Jersey, associated with spinelle, graphite, and mica. Blum†† states, that the larger granules only, appear altered. The alteration advances from the surface inwards, in the direction of the more perfect cleavage, the granules being divided into laminæ. The inner mass sometimes consists of unaltered chondrodite, while the exterior is entirely

* Poggend. Annal. lxxxii, 511.

† Neues Jahrb. für Chemie, und Physik, lxiii, 283.

‡ See ante, p. 346.

§ See ante, pp. 321, 334.

|| See ante, p. 291.

¶ Loc. cit.

** See ante, p. 362.

†† Nachtrag, p. 84.

converted into serpentine. In some of the granules, detached particles of chondrodite occur. In the larger granules, both of the altered and unaltered mineral, there are, sometimes, particles of white calc-spar imbedded.

This alteration is interesting, on account of the similarity between chondrodite and olivine in composition. Comparison of analyses of these two minerals shows, that basic fluoride of magnesium and magnesia must be separated from the former. This magnesia might be deposited as bitter-spar, as in the alteration of olivine.*

Serpentine, with the form of spinelle.—Blum † describes a pseudomorph of this kind, from Warwick, in New York. The octahedral crystals are three or four lines in diameter, and consist entirely of serpentine. The surfaces of this pseudomorph are uneven, some faces rather curved, and both edges and corners are rounded. Here and there are laminæ of graphite upon the surface of the pseudomorphs, as upon the spinelle crystals of Warwick.

With regard to the mode of alteration, I refer to the remarks relating to the conversion of spinelle into steatite.‡ As serpentine and steatite consist of the same constituents in different proportions, it is not unlikely that both may be formed from the same mineral.

The conversion of mica into serpentine has already been treated of.§ The alteration generally commences at the uneven and striated, lateral surface of the plates and columnar crystals. A soft white crust is first formed, and extends between the cleavage surfaces at many places. When the alteration is more advanced, this crust becomes yellowish and olive-green. After the alteration is complete, the pseudomorphs appear rounded at the edges, and the mass has a fatty lustre at the surface and on the fracture. In this case, as in the conversion of mica into steatite,|| there is a striation presented by the irregular granules of serpentine, corresponding with the direction of the cleavage planes of the mica.

G. vom Rath ¶ states, that labrador appears to be converted into serpentine. Near Neurode, in Silesia, for instance, there is

* See p. 361.

+ Nachtrag, 2, p. 78.

‡ See Chapter xli.

§ See ante, p. 405.

|| See ante, p. 406, and chapter xli.

¶ Poggend. Annal. xcv, 551.

a rock, consisting of labrador, as the coarse-grained, crystalline matrix, and of numerous imbedded particles of serpentine, which are generally of a long, rectangular form, with parallel sides, exactly similar to those presented by the labrador of the greenstone near Neurode, and by that of the old green-porphry. G. vom Rath considers it most probable, that the serpentine has been produced at the cost of isolated crystals of labrador. The separation of labrador and serpentine is sometimes very sharp; but, generally, the two minerals appear quite blended. The rock passes into a compact, green mass, but still contains a small amount of white labrador. The specimen examined, contained some diallage crystals which, though separated by the serpentine, were all in the same plane. The bastite presents similar characters.

	I.	II.	III.
Silica	38.78	43.70	42.36
Alumina	3.06	2.76	2.18
Oxide of manganese	0.90	....	0.85
Protoxide of iron	12.77	10.03	13.27
Lime	4.51	....	0.63
Magnesia	29.96	29.96	28.90
Potash	0.29	....	....
Soda	0.11	1.98	....
Loss by ignition	9.17	12.27	12.07
	98.55	100.70	100.26

I. The rock referred to by G. vom Rath.

II. Serpentine from Zöblitz; analyzed by O. Schmidt.

III. Bastite from the Harz; * Köhler.

Both the latter analyses are quoted for the sake of comparison. The rock represented by I, consists essentially of serpentine; but the alteration is not completed. Assuming that alumina, lime and alkalies were eliminated, the relative amounts of the other constituents would be increased, and the composition would approximate somewhat closely to that of serpentine. If this rock has really originated from labrador, silica, alumina, lime, and alkalies must have been eliminated, while protoxide of iron, magnesia, and water were introduced.

A substance analogous to serpentine, and originating from gehlenite at Monzoni, in the Tyrol, was given to me by Blum. The quantity was insufficient for more than a qualitative analysis.

* See p. 422.

The loss by ignition was 3·6 per cent. and an empyreumatic odour was evolved. The substance effervesced copiously with dilute acid, and was decomposed by hydrochloric acid, with separation of silica. The solution contained some alumina, peroxide of iron, much magnesia, but not any lime; the composition, therefore, was that of serpentine. The lime was removed by the dilute acid, and was probably in the state of carbonate. The gehlenite, separated from the altered substance, also effervesced with dilute hydrochloric acid; it lost by ignition only 0·5 per cent. It was decomposed by digestion with concentrated acid, and silica separated. The solution contained a little alumina and iron, much lime, and little magnesia, so that the mineral was already in a state of incipient alteration, having lost greater part of its alumina, although silicate of lime still remained.

The conversion of gehlenite into a substance resembling serpentine is easily to be accounted for—water containing bicarbonate of magnesia converted the silicate of lime into silicate of magnesia and carbonate of lime, the presence of which is indicated by the effervescence.

Some specimens of gehlenite sent to me by Dr. Krantz were in a very altered state. The dark greenish-black prisms presented rounded edges, and rough faces, with very small holes, filled with ochre-yellow substance. At one place there was a group of white calc-spar crystals, and the interstices between the gehlenite crystals were also filled with calc-spar.* The dark greenish-black colour of the crystals was very similar to that of serpentine; but the substance was much harder than serpentine. The crystals analyzed, were carefully separated from adherent calc-spar. I hoped to separate the carbonates by means of very dilute hydrochloric acid; but the analysis I, shows that this was not effected, for both silica and alumina were dissolved to some extent, and the feeble effervescence did not correspond with the large amount of lime obtained.

I *a* is the composition of the mineral when the iron is calculated as protoxide, and the amounts of silica, alumina, and protoxide of iron combined.

I *b* is the composition of the mineral, when, disregarding the slight effervescence, the entire amount of lime is assumed to be in combination with silica, and the loss by ignition is estimated at 1·28 per cent. The constituents included in the bracket

* This was also found by Fuchs and v. Kobell in the gehlenite analyzed by them.

marked *a*, were extracted by means of diluted hydrochloric acid; those included in the bracket marked *b*, were obtained by digesting with concentrated hydrochloric acid.

II. Analysis of crystallized gehlenite by v. Kobell.*

III. Analysis of the same by Rammelsberg.†

	I.‡	Ia.	Ib.	II.	III.
<i>a.</i> { Silica	4.75				
Alumina	5.02				
Peroxide of iron	0.91				
Carbonate of lime	11.55	11.55			
Magnesia	trace	trace			
<i>b.</i> { Silica	26.87	31.62	31.62	31.0	29.78
Alumina	18.77	23.79	23.79	21.4	22.02
Peroxide of iron	9.56	...	...	} 4.4	3.22
Protoxide of iron ....	...	9.43	9.43		1.73
Protoxide of manganese ....	...	...	...	....	0.19
Lime	24.65	24.65	31.13	37.4	37.90
Magnesia	2.84	2.84	2.84	3.4	3.88
Loss by ignition ....	....	....	1.28	2.0	1.28
	104.92	103.88	100.09	99.6	100.00

The substances represented by *Ib*, *II* and *III*, differ essentially in the amounts of iron and lime, that they contain. As, in the other analyses of gehlenite, the amount of lime is never lower than 35.3 per cent., and that of protoxide and peroxide of iron, never above 6.56, there is no doubt that in the mineral represented by *I*, a portion of the lime has been displaced by oxides of iron. This would be effected by water containing carbonate of iron, acting upon the silicate of lime,§ and the resulting carbonate of lime was deposited around the crystals. With the exception of that by Fuchs, the analyses of gehlenite indicate from 2.2 to 4.64 per cent. magnesia, so that it must be regarded as an essential constituent, and consequently it is not requisite to assume that

* Kastner's Archiv, iv, 317.

† Suppl. 3, p. 47.

‡ It is deserving of notice that the silica and alumina, extracted by the dilute acid, became black when ignited, while the silica and alumina dissolved by the concentrated hydrochloric acid did not become black. This shows in a striking manner that altered minerals, as a general rule, contain a larger amount of organic substance than those which are unaltered. There is no doubt that the portion of a mineral dissolved by dilute acid is further advanced in decomposition than that which resists solution. But where the quantity of mineral decomposed is large, the quantity of water concerned must also have been large, and the amount of organic substance deposited would be proportionately large. See ante, p. 101.

§ English edition, i, 13, No. 17.

the magnesia in the mineral represented by I was introduced from within. Therefore the alteration of the gehlenite did not tend towards formation of serpentine as was probable in the previous instance. But when, at a later time, it came in contact with water containing carbonate of magnesia, such an alteration would most probably have taken place, for there would still be enough silica of lime for producing in this way silicate of magnesia.*

As serpentine is essentially a hydrated silicate of magnesia, the remarks† made in reference to the formation of silicate of magnesia, and the conversion of different minerals into steatite, are applicable in like manner to their conversion into serpentine.

As all the regular forms presented by serpentine, are derived from the minerals from which it has originated, and are both different and unrelated, they must all be pseudomorphous, and if serpentine is capable of crystallizing, they are so, with only one exception. Bastite and chrysotile have been regarded as serpentine, as both have a composition very similar to serpentine. If bastite is, as G. Rose considers, a product of the alteration of augite, this would be a further instance of the conversion of augite into serpentine substance. The delicate threads of chrysotile occurring in the small dykes in serpentine, appear to be imperfect crystals; hence it may be inferred that substances having the composition of serpentine are capable of crystallizing.

As serpentine does not present any individual crystal form, it is impossible to determine whether it is displaced by other substances. Nor is there any instance known in which any mineral has been displaced by serpentine.

SERPENTINE ROCKS.

Compact masses not unfrequently occur, together with serpentine, in such a manner as to suggest the probability of alteration. The close connection between gabbro and serpentine has already been alluded to.‡ According to G. Rose, these two substances often occur so intimately mixed, and the serpentine is so far preponderant, as at many places near Volpersdorf, in Silesia, that the pure gabbro appears only as the remains of a mineral that has not yet been converted into serpentine. V. Buch states that in

* English edition, i. 13, No. 16.

† See Chapter xli.

‡ See ante, p. 334.

the dolomite, which occurs as a bed in crystalline schistose rocks, near Rothzechau, in Silesia, there are veins of serpentine, at the utmost, an inch and a half thick. G. Rose is of opinion that in this latter instance, the serpentine is a product of the alteration of dolomite. Assuming that the dolomite contained the silicates of which the serpentine consists, no objection can be offered to this view.

The conversion of diorite into serpentine has already been referred to.* Kupffer† speaks of an intimate association of serpentine and diorite, at the eastern declivity of the Ural mountains. F. Sandberger‡ also mentions an instance of the association of diorite with a rock resembling serpentine, so intimate that the latter appears only as a modification of the former.

Instances of the transition of serpentine into chloritic and talcose schist have long been known. The intimate relation between chlorite and serpentine, will be illustrated subsequently by the characters presented in the serpentine at Greifenberg.

Serpentine frequently occurs at the junction of two rocks, where alteration naturally takes place most readily. Thus, Reuss§ states, that at the northern declivity of the Forca Rossa, near Pedazzo, there is a stratum of serpentine, from one to two feet thick, and a layer of green, fat clay, five or six feet thick, between the granular limestone, and the syenite. The syenite itself is decomposed and ferruginous to a considerable distance. There can be no doubt, that in this instance, the hornblende of the syenite furnished the material for the serpentine; and the felspar, that for the clay.

Fallou|| and H. Müller¶ describe the masses of serpentine occurring in Saxony, at Waldheim and Greifendorf. Fallon merely gives the geognostic facts; Müller speculates as to the mode of origin. Both memoirs are replete with facts and furnish an explanation of several interesting relations, though I cannot agree with the views entertained by the latter observer. Both observers regard the serpentine as a conformable stratification in

* See ante, p. 417.

† Poggend. Annal. xvi, 272.

‡ Uebersicht der geolog. Verhältnisse von Nassau, p. 65.

§ Jahrb. f. Mineral. etc., 1840, p. 153.

|| Archiv. für Mineral. etc., xvi, 423 et seq. Ten years since, Fallon sent me a complete collection of specimens from the serpentine of Waldheim. They contain abundant material for chemical investigation which would clear up many observed relations. I have not been able to do more in this direction than the analyses subsequently quoted.

¶ Jahrb. für Mineral. etc., 1846, p. 257 et seq.

the granulite. The individuality of the serpentine at Waldheim is denied by Fallou. The underlying rock is undoubtedly gneiss.

According to Müller's observations, the frequently recognizable transition of eklogite into serpentine, and the presence of garnet in the latter, seem to indicate that the serpentine is altered eklogite. The frequent transition of eklogite into granulite, and their conformable stratification, indicate that the original rock, from which the serpentine has been produced, must have been of the same antiquity as the granulite.

Granulite almost always contains granules of garnet, generally the size of peas, but sometimes barely recognizable. At some places, it contains hornblende, and passes into the trap-granulite, and lastly into eklogite. The eklogite consists of small granules of hornblende, with numerous brown and red garnet crystals imbedded.

The chlorite dykes traversing the serpentine at Greifenberg, in all directions, are an important feature. They are filled, either, with chlorite alone, or with chlorite and other minerals and rock masses, passing into each other. The pure chlorite dykes are so abundant, that they may generally be seen in every part of the rock, while the dykes with mixed contents occur only at some parts. Frequently, chlorite dykes traverse the serpentine in all directions, in one quarry; and it is only seldom that they run parallel. Their frequent branching is remarkable, and is connected with disturbances of the rock that are often considerable. The chlorite dykes are frequently intruded after the manner of beds, between the masses of serpentine.

The fragments of foreign rocks and minerals, imbedded in the chlorite dykes, consist of granulite, granite, eklogite, serpentine, and actinote. Although in most of these dykes, fragments of rocks occur, that are also associated with the serpentine, still it is not unfrequent, that there are fragments of rocks and minerals, that occur only at some distance, or not at all at the surface.

Fallou's observations of the serpentine at Waldheim, are directly opposed to the opinion entertained by Müller of the eruptive origin of the chlorite dykes. Chlorite, talc, steatite, actinote, chalcedony, and calc-spar are associated with the serpentine only, and ramify into it, while these minerals do not occur as dykes in either the granulite, or the other members of the rock.

The simplest explanation of the production of these chlorite dykes obviously suggests itself. Assuming, as Müller does, the

serpentine existing, and, instead of the violent rending and dislocation of the rock, a gradual and slow fissuring, in consequence of the alteration of volume attending the conversion of eklogite into serpentine, all the conditions for the productions of these chlorite dykes would obtain.

Müller himself states, that at many places, the serpentine passes into a chloritic or talcose mass. This alteration of a hydrated rock into another hydrated rock, can have been effected only in the wet way, and this is the more evident, as the fissured condition of the rock would facilitate the access of water.

The minerals constituting eklogite and granulite contain alumina. In their conversion into serpentine, this earth would be eliminated. But chlorite contains alumina as an essential constituent. Consequently, water would remove from the rock alumina with a corresponding amount of silica, magnesia, and protoxide of iron, depositing them in the fissures as chlorite, while the residual mass was converted into serpentine.

As chlorite and serpentine contain silica, magnesia, and water, in nearly the same proportions and as the amount of protoxide of iron in these minerals varies, within the same limits, chlorite may be regarded as serpentine plus alumina, and serpentine may be regarded as chlorite minus alumina. But where the presence or absence of a single substance determines the production of one or other mineral, the passage of one into the other is readily intelligible; too much alumina in serpentine renders it chloritic; too little alumina in chlorite renders it analogous to serpentine. Although the conversion of serpentine into chlorite, by introduction of alumina, may be regarded as possible, still this alteration is not very probable and the contrary is much more probable.

Pseudomorphs of serpentine after chlorite have not been observed; perhaps, because chlorite seldom occurs as distinct crystals. In such an alteration, there would be an elimination of alumina, and as this takes place in the conversion of garnet and mica into serpentine the possibility of the alteration cannot be doubted.

As the alteration of the original rock has taken place, not only at the interior, but also, still more at the sides of the fissures, where water most readily had access, the production of chlorite dykes from one line to three feet in thickness, would be determined by the facility with which water gained access.

If there were upon the sides of the fissures masses which more or less resisted the alteration, they would be gradually envel-

seen in the granite itself. But they might be so disguised by partial alteration, that their similarity to the masses occurring at the surface would be in almost total ignorance.

Not far from a large chlorite dyke, which contains fragments of granulite, there is an elongate rock traversed by numerous veins of chlorite and quartz, and passing above and laterally into serpentine. At the lower part, however, it presents a greater similarity, and there is not any sign of alteration.

There, then, there appears to be a more rapid alteration near than at a distance. The progressive alteration towards the upper and lateral portions of the rock shows that it followed the same course as the surface water. If the alteration had been effected by igneous action, or by any influence exercised from below, the lower parts of the rock would have been most affected, and this is just the reverse of the observed conditions.

Towards the upper and lateral parts of the eklogite, the hornblende loses lustre and hardness, gradually assuming the character of serpentine. The garnet generally remains unaltered, but sometimes loses its hardness and lustre. At some parts it becomes covered with an incrustation of fine laminar chlorite, like the garnet in serpentine: and sometimes, it is entirely converted into chlorite. The greater the extent to which eklogite is converted into serpentine, the more general is the conchoidal structure: the outer shell is then generally serpentine; the inner nucleus pure eklogite. This shows distinctly that chlorite is the first product of alteration, and that serpentine is the last.

The conversion of granulite into serpentine, is very distinct at one place. The yellowish or blueish-white granulite becomes greenish-grey, or pale green: loses its crystalline appearance and hardness, passing gradually into very soft serpentine, in which the mica of granulite may sometimes be recognized. At a higher point, this serpentine becomes harder, and presents the ordinary blackish-green colour.

In this instance, also, the alteration progresses from the surface downwards, and is facilitated by the numerous fissures in the rock. If the lower portions of this rock are not altered to such an extent as the upper parts, and this can scarcely be doubted, it will be seen that the softening, which takes place during the earlier stages of alteration, disappears again when the alteration is more advanced. Müller observed, that sometimes the masses of serpentine near chlorite dykes were considerably contorted. This character may have resulted from the softening

of the rock during the alteration, which would take place most, near the dykes.

Fragments of granite, often with sharp edges, are found in the chlorite dykes, that have a thickness of four feet. The felspar, which is full of large laminæ of mica, and, like the granulite, is imbedded in chlorite, has distinct lustre, hardness, and cleavage at the centre; at the exterior it passes gradually into pyknotrope. Sometimes fragments are found, which have a cleavage exactly like that of felspar; but in other respects have the characters of noble serpentine. In some unaltered fragments, the mica is blackish-brown, or pinchbeck-brown; in those which are more altered, it is violet or greenish, and softer, finally assuming the aspect of chlorite. At one place, the felspar is steatitic* in appearance, and the quartz is replaced by a soft steatitic substance.† Both substances pass gradually into talc or noble serpentine. The mica sometimes appears chloritic. Many of these granite fragments are rounded; and, frequently, there is, at the centre, a nucleus with granitic texture; but at the outer portions, the concentric layers gradually pass into serpentine, and the outer crust often consists merely of compact talc. A few of these fragments are converted into soft talc, mixed with much chlorite; and the previous existence of granite can be recognized only by tracing the gradual transition.

In the case of granite consisting only of quartz, felspar, and mica, it is the latter which is converted into serpentine,‡ and the felspar which is converted into chlorite.§ The conversion of orthoclase into serpentine has not yet been observed; but as it is susceptible of conversion into chlorite, which is so nearly related to serpentine, and as there is much probability that labrador is susceptible of conversion into serpentine,|| it is possible that such an alteration may take place. Indeed Weibye¶ states that in one of the mines near Arendal, masses resembling serpentine, are associated with imbedded crystals which appear analogous to felspar.

The fragments of eklogite, in the serpentine at Greifenberg, are generally quite fresh, but rounded, and the garnet at the surfaces is incrustated with chlorite, which sometimes entirely

* It is questionable whether the substance is steatite. See ante, p. 173.

† English edition, i, 19, and ii.

‡ See ante, p. 405.

§ See ante, p. 173.

|| See ante, p. 419.

¶ Loc. cit.

replaces the garnet. Frequently they present a conchoidal structure, and then the hornblende of the outer layer, is generally converted into serpentine, while the eklogite at the interior of the mass is unaltered. Several of the larger fragments are traversed by thin threads of chlorite, which undoubtedly represent the fissures in the original rock, by which water penetrated into the mass. In the midst of some of the chlorite dykes at Greifenberg, there are fragments of serpentine more or less rounded, and presenting generally the same characters as the surrounding rock.

It follows from the observations recorded by Müller, that granulite, eklogite, and granite, have been converted into serpentine, chlorite, steatite, and talc.

The quartz dykes, in the serpentine, are much less numerous than the chlorite dykes, and are only an inch and a-half or two inches thick. Sometimes the quartz encloses small sharp-edged fragments of serpentine, and at the saalbands it is frequently separated from the adjoining rock by a thin talcose or chloritic layer. At one place a quartz dyke extends between the slabs of serpentine and ramifies into them. It is intersected by a chlorite dyke containing fragments of granulite.

The presence of quartz dykes indicates elimination of silica, and this is consistent with what might be anticipated when a rock, containing more silica and less magnesia than serpentine, is converted into serpentine, without silicate of magnesia being introduced from without. The principal constituents of eklogite are of this kind, for instance, smaragdite and garnet. In the conversion of the felspar of granulite into chlorite, still more silica would be eliminated. As the quartz dykes are intersected by a chlorite dyke, the former were filled before the rock was converted into chlorite. Consequently the elimination of silica preceded the formation of chlorite; indeed the quartz of the granulite might have been displaced by steatite.*

Veins of brown iron ore also occur in the serpentine at Greifenberg. One of them, four feet thick, traverses the serpentine between the granulite and the overlying eklogite. In this vein there are nodules, containing gneiss, frequently quite converted into brown iron-ore. Near this vein, the serpentine and eklogite are very much altered.

It might be conjectured that the gneiss was carried mechanically into these dyke fissures and decomposed there; in any case, large fragments of gneiss, well preserved, occur at some little dis-

* See Chapter xlii.

tance upon the surface. The hydrated peroxide of iron, forming the cement between the nodules, appears to originate partly from decomposed gneiss, and partly from adventitious water containing iron. As the red garnet and, generally, the aluminous hornblende, contain much more iron than serpentine, there would be a considerable elimination of iron during their conversion into serpentine.

From the observations recorded by Fallou, and from facts he has communicated to me, it would appear, that the remarkable correspondence of structure presented by the granulite and serpentine at Waldheim, the detached slab-shaped masses and the vertical fissures presented by both rocks, except at the boundaries, are in favour of the opinion that the granulite has been converted into serpentine. The thickest chlorite dykes are quite parallel to the fissures in the granulite.

Fallou considers that my opinion with regard to the origin of the chlorite dykes is quite correct and he opposes Müller's conjecture that they were erupted. The substance contained in all dykes traversing serpentine is in a constant state of alteration. The fissures were originally empty, and were filled in consequence of the decomposition of the adjoining rock. The dislocation, disruption, and similar effects, were caused by the sinking of the mass which the loose chlorite was unable to support, and which slipped downwards along the divisional planes situated at an angle of 30° to 40° . Where the mass again became fixed, the slabs of serpentine are fractured and protruded into each other.

The rough, granular exterior of the slabs of serpentine at Waldheim, is generally covered with yellow or white mica, especially where the planes of bedding are filled with chlorite. In the mass of the serpentine, mica occurs less frequently, and only in the black, or blackish-green varieties; where it appears as layers of small white laminæ. In dykes, the interior of which consists of granulite or felspar, passing into pyknotrope towards the sides, laminæ of brown, lustrous mica frequently occur detached, or as adherent nodular masses. It occurs less frequently in the brown and grey pyknotrope, at the Wachberg; there it appears as long, narrow, dark-brown laminæ, sometimes intersecting, and firmly attached to the surfaces of fracture. In indurated talc this mica is characterized by the copper-red, and violet tinge, and occurs in detached laminæ, sometimes several inches broad, especially where the dykes contain compact angular fragments of felspar, pyknotrope, and talc.

If the serpentine at Waldheim, is altered granulite, and if mica has not been produced during the alteration, the mica found must belong to the original rock. In granulite it occurs but scantily; for the most part near the serpentine, while in the variety resembling gneiss it is in larger amount. Sometimes it occurs only at the planes of cleavage of the detached slabs, and appears frequently mixed with hornblende. It is in all cases blackish-grey or brownish. In the serpentine, mica occurs, which is white, yellow, black, blackish-green, brown with high lustre, copper-red, and violet colored. The silver-white mica occurs only at the outer surfaces of the slabs as a delicate film. Owing to the great diversity of both kinds of rock, the relative proportions of mica that they contain, cannot easily be estimated. So far as it is possible to judge from the masses at the surface, the proportion in serpentine may be about $\frac{1}{10}$, and in granulite about $\frac{1}{5}$. In the latter rock the proportion of mica is the same at different points in a vertical direction; but in serpentine the amount of mica is small at the greater depths, evidently showing that it is a product of the alteration, which advances from the surface downwards.

Among the specimens sent to me by Fallou, there is one with the description, "chlorite between granulite and serpentine; from Saalbach, near Waldheim." As chlorite seems to have such an important connection with the serpentine of this locality, I subjected this mineral to analysis. The cleavage was imperfect, and upon the surfaces of cleavage there were small, bright laminæ lying in various directions; in reflected light they appeared partly greenish-white, and partly pinchbeck colored, at some places red and blue also. Where the light is not reflected, the mass appears dark, or blackish-green, and the laminæ aggregated at the edges have the same appearance. The whole mineral might be compared to an irregular heap of different kinds of mica laminæ. The quantity was too small to admit of the separation of the evidently different substances. But to effect this object as much as possible I powdered the mineral very finely and submitted it to the following treatment.

The mineral contained, after drying at 212° F., 1.13 per cent. water. Intense ignition caused an increase of weight, amounting to 0.44 per cent., doubtless in consequence of peroxidation of iron. Dilute hydrochloric acid did not produce any sensible effervescence. As ignited chlorite is dissolved by hydrochloric acid; the ignited mineral was digested with this acid. However, the

substance extracted amounted to only 7·44 per cent., and consisted of:—

Alumina and peroxide of iron	....	....	3·55
Lime	....	....	0·45
Magnesia	....	....	1·66
			<hr/> 5·66

As the deficiency here is very considerable, the presence of **alkalies** may be conjectured. The silica separated by digesting the minerals with hydrochloric acid contained shining, pearly **laminæ**, which might be separated, by washing, from the pulverulent silica. Although v. Kobell* remarked, that when uniaxial **mica** is decomposed by means of concentrated sulphuric acid, the silica remains with this form, it appeared worth while to examine these **laminæ** which so closely resembled mica. They amounted to about three times as much as the pulverulent silica, and the quantity was sufficient for an analysis. After treatment with hydrofluoric acid there remained 10·47 alumina and peroxide of iron, 0·11 magnesia, and there was a distinct indication of the presence of **alkalies**.

For the quantitative analysis, the mineral was decomposed by digestion with concentrated sulphuric acid; it consisted of:

	I.	II.
Silica	47·43	47·43
Alumina	13·77	13·77
Peroxide of iron ..	16·98	15·45
Magnesia	15·42	15·42
Potash	5·17	5·17
Soda	1·38	1·38
Water	1·13	1·13
	<hr/> 101·28	<hr/> 99·75

The silica separated in this analysis also contained several shining, pearly **laminæ**, which, after treatment with hydrofluoric acid, left 1·79 alumina and peroxide of iron, 0·46 magnesia. It was not ascertained whether these **laminæ** also contained **alkalies**.

As the quantity of these **laminæ** could be estimated only approximatively, it was not possible to correct the analyses

* Kastner's Archiv. xii, 35.

according to the amount of bases retained in the laminæ, so that the bases are estimated too low, and the silica somewhat too high.*

As the iron is, for the most part, in the state of protoxide, the analysis was corrected in this respect, in II. Lime was extracted from the minerals by treatment with hydrochloric acid, in estimable quantity; but in the last analysis there was not a trace found. It would seem, therefore, that this earth is unequally distributed throughout the mass, probably as carbonate of lime, although, certainly, it did not effervesce with acid. There was not a trace of manganese.

Consequently the mineral is not chlorite, but magnesian mica, with a somewhat large amount of silica. In other respects it must remain an open question, whether or not this mineral is a mixture of several kinds of mica, perhaps with chlorite also. The colours presented by it would indicate that this is the case, and the imperfect cleavage, admits of the inference, that the conversion into mica was not fully completed, and that there was some uncombined silica between the laminæ, as is so often the case with pseudomorphous mica.

According to the results of this analysis it would appear somewhat doubtful, whether the dykes, which occur so frequently in the serpentine of Greifenberg and Waldenburg, always contain chlorite, or whether mica has not, in some instances, been mistaken for chlorite. In any case it is much to be desired that this point should be decided by analyses.

It cannot be ascertained what mineral the mica has originated from in this instance. As the mica occurring upon the cleavage surfaces of the detached slabs† is frequently mixed with hornblende, it is possible that this mineral may have furnished the material for the formation of mica.‡ It is only the white mica, which occurs so seldom, that can originate from the alteration of felspar.§ However, when the different minerals constituting a rock, undergo in common, conversion into serpentine, it is the products of the decomposition of all that contribute to the formation of new minerals. Consequently, it is possible, that the felspar may have furnished the alkaline silicates for all the mica

* It is highly probable that the silica separated from magnesian mica, by means of sulphuric acid, always contains bases. In future, therefore, the silica obtained in analyses should be treated with hydrofluoric acid and the residue tested for bases.

† See ante, p. 429.

‡ See ante, p. 350.

§ See ante, p. 172.

formed, since these silicates have not otherwise been concerned in the alterations observed at this place.

The granulite breccia shows what varied alterations have taken place in granulite. This rock consists of a mass of broken granulite, stratified in undulating layers, unequally inclined in all directions; and thus presenting a position quite different from that of the adjoining granulite. It consists chiefly of angular fragments of granulite, from one to twenty-four inches in diameter, alternating with separate layers; and, sometimes, thick beds of ferruginous quartz, serpentine, pulverulent serpentine, and loose schistose mica-clay. The latter also contains nodules of granulite and hornblende rock, and blocks of ferruginous quartz. The larger masses of the ferruginous quartz are sometimes covered with a shining crust of talc, which also occurs as layers and nests, while the thickest beds of ferruginous quartz sometimes contain druses of quartz and calc-spar. The beds of serpentine, alternating with ferruginous quartz, are so fissured, that the mass readily breaks into fragments; sometimes arragonite occurs upon the fissures.

The constituents of this breccia show what substances are eliminated from the rock before it is entirely converted into serpentine. All those minerals that are foreign to it, such as the ferruginous quartz, must, at subsequent periods, be removed by water.

The serpentine tuff that adjoins this breccia, at both sides, is also analogous to breccia, and consists of earthy, black or reddish-brown serpentine, full of ferruginous quartz, black iron-ore, (pselomelane?), and chlorite, as well as quartz and hornblende. At some parts, the soft matrix passes into compact slabs of serpentine, alternating with chlorite, and the fragments are covered with calcareous tuff. In the overlying beds, the serpentine-tuff borders upon the normal granulite, and the ferruginous quartz appears blended with it. In the underlying beds, the granulite is converted, to the distance of about fifty yards, into a friable mass, although it still retains its structure and bedding. At the other side the serpentine breccia passes, at places, into beds of ferruginous quartz; and these pass into granulite breccia, containing fragments of ferruginous quartz in cavities. There is also a vein of asbestos traversing these beds of fragments.*

* Delesse—Jahrb. für Mineral. 1848, p. 257—analyzed a specimen of asbestos of this kind occurring in the dykes, not exceeding one or two centimeters thickness, which traverse the serpentine of the Vosges in all directions. The very thinnest fibres are at right angles to the sides of the dykes, and have the composition of v. Kobell's chrysotile.

The characters of the bedding of these masses admit of the conjecture, that serpentine breccia has not originated from decomposed serpentine. The amount of silica in serpentine varies only between 45 and 40 per cent.; in most instances it differs little from the amount calculated from the theoretical formula.* If, therefore, the compact serpentine contained the normal amount of silica, the ferruginous quartz, and ordinary quartz, contained in the serpentine tuff, cannot have originated from silica eliminated from the serpentine.

Fallou informs me, that in the construction of the Chemnitz railway, serpentine was found, west of Waldheim, that was converted, to a depth of ten feet, into chloritic clay.† In these fragments of *débris*, which lie twenty feet below the surface, all the stages of the decomposition may be traced, and they contain a nucleus of the compact rock. This serpentine, therefore, the products of its decomposition, and its great dissimilarity from the serpentine tuff, thus furnish further evidence against the opinion, that the tuff originated from the serpentine. It is much more probable, that the breccia-tuff is still in progress of conversion into serpentine.

The above descriptions show, that by the decomposition of eklogite and granulite, the whole of the products of decomposition which contain silicate of magnesia, may be formed. These are serpentine, chlorite, talc, and steatite, but the serpentine preponderates. There is no doubt that mica should be included among these products of decomposition, and the blackish-green, brown, and copper-red mica occurring in the serpentine, is, undoubtedly, magnesian mica, like the specimen analyzed.

The silicate of lime in the hornblende and garnet, is reduced to a minimum; the above-mentioned incrustations of calc-spar, etc., are the remains of these decomposed silicates, but by far the greater part of the carbonate of lime has certainly been removed by water.

The considerable masses of ferruginous quartz, show, that the iron and silica of the decomposed rocks, have only partially passed into products of decomposition containing silicate of magnesia, and

* See ante, p. 416.

† Chemical examination must determine whether this clay is really chloritic, and whether, therefore, serpentine is capable of taking up alumina. As serpentine, when finely powdered, is completely decomposed by sulphuric acid, and by concentrated hydrochloric acid, it is possible that it may also be decomposed by carbonated water; but even in that case chlorite would not be formed.

a certain amount of these substances has certainly been removed by water.

It would be difficult to determine whether silicate of alumina was abstracted from the entire mass of rock, or whether the alumina in the chlorite, and the mica, is equivalent to that contained in the original rock. Moreover, it may be conjectured, that during the alteration, some minerals, previously existing, have been reproduced; this is certain, with regard to mica, and not improbable with regard to hornblende, for Fallou found a quartz nodule imbedded in hornblende.

If hornblende, augite, and garnet, containing the largest amount of magnesia—the tremolite of Gällsjö; the augite of Pargas, and the black garnet of Arendal—were converted into noble serpentine, like that of Fahlun, without alteration of volume, the percentage amount of the substances eliminated and introduced would be :—

	I. Hornblende.		II. Augite.		III. Garnet.	
	Elimi- nated.	Intro- duced.	Elimi- nated.	Intro- duced.	Elimi- nated.	Intro- duced.
Silica	25·90	...	23·43	...	15·86	...
Magnesia ....	...	7·80	...	8·40	...	12·34
Lime	14·11	...	15·70	...	6·53	...
Protoxide of iron ....	...	1·29	0·81	...	7·88	...
„ „ manganese ....	...	...	0·43	...	6·27	...
Alumina ....	...	0·30	2·55	...	22·24	...
Bitumen and Carbonic acid ... }	...	2·76	...	2·61	...	2·17
Hydrofluoric acid	0·94	...	...	...	...	...
Water ....	...	9·32	...	8·90	...	7·41
	40·95	21·47	42·92	19·91	58·78	21·92

In the conversion of these three minerals, the first and last of which chiefly occur in eklogite and granulite, it is evident that considerable amounts of magnesia must be introduced, supposing that the volume is not altered. These quantities would be still more considerable if the minerals did not contain much magnesia. As the alteration at Greifenberg and Waldheim, progressed from the surface downwards, it must have been effected by surface water and not by the water of springs rising from below. But then the water would have abstracted magnesia, either as carbo-

nate or silicate, from the upper parts of the rocks near the surface, and conveyed to the lower portions, so that the entire mass of the rock would have experienced an absolute loss, for silica and lime must have been eliminated from all the above-named minerals, for the conversion into serpentine to have taken place. But in this case, the upper portion of the rock would have been deprived of the requisite condition for conversion into serpentine.

If, however, magnesia was not supplied to the eklogite and granulite by water, their complete conversion into serpentine could only have been effected by the elimination of still larger amounts of silica than the above calculations point out, and one consequence of this would be, the considerable diminution of the volume of the rock. In both cases there must have been a depression of the mass, greater in the latter, than in the former case, because the decomposition extended further.

This abstraction of substance, that progressed gradually, is certainly adequate to account for the dislocation observed, and it is quite unnecessary to have recourse to hypotheses of convulsive disruptions by any means.

The silica eliminated occurs in the state of ferruginous quartz. The alumina, protoxides of iron and manganese, that would be eliminated in the conversion of hornblende and augite into serpentine, are of small amount and need not be taken into account; but in the conversion of garnet into serpentine, the amount of bases eliminated would be considerable. The iron occurs in ferruginous quartz, the manganese as psilomelane. The alumina can be found only in the chlorite and mica, probably only to a partial extent. When the amount of these products of decomposition, occurring in serpentine, is large, it may be conjectured that the original rock contained a considerable amount of garnet.

Fournet* records some valuable observations relating to the serpentine, occurring in the Alps, between Wallis and Oisans, which presents characters of alteration similar to those of the Saxon serpentine. At Mont-Jovet, in the Aosta valley, hornblende rock alternates innumerable times with limestone, containing serpentine, eklogite, quartz, mica, or garnet. The last-named mineral is also found imbedded in serpentine, as in the valleys of Chamouni and St. Nicolas, in Wallis; or it occurs crystallized, in fissures, as near Mussa in Piedmont; sometimes the crystals are found upon the sections of veins.

Fournet considers that water, carbonic acid, and even bitumen,

* Jahrbuch für Mineral. 1846, p. 363.

have taken part in the formation of this rock; he supposes that silicates were decomposed by carbonic acid, and separated from the siliceous and talcose mass; but he considers that the greatest obstacle to the separation of the different elements of the serpentine, exists in the slight fusibility of the silicates of magnesia. The same difficulty would always be encountered in attempting to account for the formation of rocks by fusion.

It has been shown that, in the alteration of garnet into serpentine, there is a considerable elimination of alumina. The decomposition of felspar furnishes quantities equally great. If the alteration were not accompanied by an equivalent production of chlorite and mica, and the alumina were not removed, as silicate, by water, the serpentine produced would contain a considerable amount of silicate of alumina. As serpentine has no peculiar crystal form, the presence of this silicate would be no obstacle to the production of serpentine. It might, therefore, happen that the product of alteration would consist of only 1 per cent. serpentine, with 99 per cent. silicate of alumina, although such mixtures would not be called serpentine. Kerolite, dermatine, antigorite, spadaite, chonikoite, pyrosklerite, remalite, retinalite, prasilite, picrosmine, monradite, villarsite, etc., are described as minerals that are closely related to serpentine, and they have, most probably, originated from other minerals by alteration. Sometimes they do not contain any alumina; but the greater number do contain some alumina, from 0·3 to 17 per cent. There is no doubt that all these minerals are susceptible of conversion into serpentine, if the alumina were eliminated wholly or for the most part.

Delesse* has instituted a very valuable chemical examination of the serpentine of the Vosges. It contains the following minerals, sometimes imbedded, and sometimes in small dykes. Garnet is most frequent in the matrix. It contains 41·56 per cent. silica, the same as the serpentine in which it occurs. Both the garnet and the other silicates in the serpentine, contain some chromium. Chrome iron-ore, and magnetic iron-ore, are very frequent in the serpentine of the Vosges. The former is sometimes found at the interior of masses of garnet, either irregularly disseminated, or as concentric zones. Iron pyrites is rare, especially in the garnet. Bronzite appears, sometimes disseminated through the matrix, but generally in larger masses, or it follows the dykes, which are connected with serpentine at the saalbands,

* Ann. des Mines. Sér. 4, xiv, 476.

and traverse it in all directions. In composition it approximates to the bronzite previously described.* It contains 1·5 per cent. oxides of chromium and manganese.

The serpentine of the Vosges contains chlorite, which occurs in small veins, and at the interior of the masses of garnet, especially those situated near the veins. Pseudomorphic changes have been going on here, and the garnet has been gradually converted into chlorite.† It is, moreover, very probable that the production of these pseudomorphs is not yet completed. The chlorite contains 1·49 per cent. oxide of chromium.‡

The conversion of garnet into chlorite is not a mere local phenomenon, it is observed to some extent in all the serpentine of the Vosges. With regard to the mode in which this alteration is effected, it is probable that the reaction pointed out as taking place between silicate of lime, and bicarbonate of magnesia,§ is concerned.

In the serpentine of Tholy, of Neymont and Corcieux, the bronzite dykes are frequently accompanied by chlorite. In the serpentine at Xettes, very fine chlorite occurs, as large blueish-green, transparent laminæ, associated with veins of calc-spar. In the serpentine at Goujot and Col de Bonhomme, there are pale green laminæ of chlorite, with a pearly lustre, and containing less iron.

The serpentine of the Vosges, like that of all other localities, is traversed by numerous dykes of chrysotile, resembling asbestos. This mineral is not fibrous serpentine, but, according to the analysis by Delesse,|| serpentine and chrysotile appear to be dimorphous conditions of the same compound.

The noble serpentine also forms dykes in the serpentine matrix. Both kinds frequently contain chrome iron-ore, and the diversified colour of the former indicates differences in the amounts of chromium and iron. Carbonate of lime is very frequently associated with noble serpentine. Probably it is a product of the alteration of impure serpentine, which is sometimes slightly calcareous, while the noble serpentine, and all kinds that are pure, do not contain any lime.

Sometimes the serpentine in the Vosges, contains dolomite, but it is always accidental. Small crystals of specular iron-ore

* See ante, p. 332, No. vii.

† See ante, p. 290.

‡ See ante, p. 407, note.

§ English edition, i, 13, No. 16.

|| Jahrb. für Mineral. etc., 1848, p. 257.



occur in it, and, like the serpentine at Greifenberg and Waldheim, it sometimes contains granitic masses.

The following analyses are by Delesse.

	I.	II.
Silica	40·83	42·26
Alumina*	0·92	1·51
Protoxide of iron	7·39	7·11
„ „ manganese	trace	...
Lime ...	1·59	0·80
Magnesia	37·98†	38·90
Oxide of chromium	0·68	...
Loss by ignition	10·70	9·42
	100·00	100·00

I. Blackish-green matrix of the serpentine at the Col de Pertuis.

This mineral was decomposed by hydrochloric acid, the silica separating in a granular state; but the decomposition was not complete.

The admixture of garnet amounted to 4·17 per cent., or rather less.

II. Chesnut-brown serpentine from Goujot, containing green veins, with reddish and green garnet.

Both these specimens of serpentine differ much in composition from the above-mentioned normal composition. Both analyses show that the matrix of the serpentine containing garnet, does not contain more alumina than that which does not contain garnet, and, consequently, that the alumina belongs to the garnet. The brown colour of the mineral represented by II, is owing to the presence of oxides of iron; but it is remarkable that the amount of iron in both minerals is nearly the same.

The oxide of chromium in the mineral represented by I, appears to originate partly from decomposed chrome iron-ore mixed with it. The serpentine represented by II, contained only traces of chromium, and this is the case with all the serpentine of the Vosges, whatever may be its colour.

The enormous serpentine bed at Snarum, is surrounded by gneiss, according to the description by Böbert.‡ At all sides the

* Contained chromium and manganese.

† Estimated from the deficiency.

‡ *Gaea norvegica*, Heft. i, p. 137.

gneiss is succeeded by a very extended layer of quartz; then comes a mixture of quartz and bitter-spar, then tolerably pure bitter-spar, which passes into common serpentine, with a nucleus of noble serpentine, and, at the centre, there are indications of the formation of steatite.

A comparison of the analyses of olivine with those of the serpentine from Snarum,* shows that, during the conversion, silicate of magnesia and protoxide of iron would be eliminated from the olivine, while alumina, as well as water must be introduced, in order that there should not be any diminution of volume. The silica occurs in the quartz beds; the magnesia as bitter-spar. To judge from the characters of the serpentine beds at Greifenberg and Waldheim, the protoxide of iron eliminated, would perhaps be found in the quartz beds.

In the conversion of hornblende, augite, or garnet, into serpentine, it has been shown that, either magnesia must be introduced, or a larger amount of silica must be eliminated; but in the conversion of olivine into serpentine, magnesia is eliminated, and this is the only case in which it occurs.† This circumstance is quite in accordance with the fact, that the serpentine bed at Snarum is surrounded by bitter-spar, and that this mineral traverses throughout, several of the varieties of serpentine in that locality. It is also in accordance with the fact that, in the serpentine beds in Saxony, which have not originated from olivine, bitter-spar either does not occur, or there is only a very small amount in drusy cavities.

If, in the production of the serpentine at Snarum, there was a diminution of the volume of the mass, as was unquestionably the case in the production of the serpentine in Saxony, the quantity of the substances eliminated would amount to more than is indicated by calculation. The considerable masses of quartz, and bitter-spar surrounding the beds of serpentine at Snarum furnish

* See ante, p. 362.

† The analyses of decomposed olivine, quoted at p. 364, show that elimination of magnesia is a general feature of the decomposition of olivine. The olivine referred to at p. 359 (No. v), also presents indications of alteration in its brownish colour, and the partial loss of magnesia. It contains :—

Silica	....	....	....	....	44·69
Magnesia	....	....	....	....	40·92
Protoxide of iron	...	....	....	....	14·22
					—
					99·83

The amount of magnesia here is much less, and that of protoxide of iron much greater than in normal olivine. When this decomposition is attended with complete peroxidation of the residual iron, serpentine cannot of course be formed.

strong evidence in favour of a diminution of volume having taken place.

The largest amount of alumina that has hitherto been found in olivine, is 0·22 per cent. If the olivine at Snarum contained as much, still, in the production of serpentine, alumina must have been introduced from without. Consequently some other aluminous mineral must have existed there, and this corresponds with known association of olivine with other minerals.* Thus, for instance, the olivine might have occurred in hornblende rock, as at the Huron lake, and it may be easily understood that the whole rock might be converted into serpentine, the hornblende supplying the alumina of which the olivine was deficient. In this case, the excess of magnesia in the olivine might have compensated for deficiency of this base on the part of the hornblende, to such an extent that there would not be any elimination of magnesia, and consequently no formation of bitter-spar.

If the olivine at Snarum had been mixed with such a mineral as that, resembling bronzite, and occurring in the olivine masses at the Dreiser Weiher,† the 4·21 per cent. of alumina that it contains would have supplied this earth in sufficient amount for the formation of serpentine. Moreover, there cannot be any question as to the possibility of the conversion of bronzite into serpentine, since augite is susceptible of a similar alteration.

Decomposition.—Decomposed serpentine has already been alluded to;‡ but as there are not any published analyses, nothing further can be said about it.

CHAPTER XLI.

STEATITE, TALC, AND MEERSCHAUM.

STEATITE and talc are not acted upon by acids, either before, or after ignition; meerschaum is decomposed by hydrochloric acid, the greater part of the silica separating as flocks.

Occurrence.—Steatite occurs in micaceous schist, gneiss, granular limestone, serpentine and granite; in both the latter rocks it occurs upon dykes. It occurs also as small nodules, and upon

* See ante, p. 356.

† See ante, p. 332.

‡ See ante, p. 434.

veins of basalt; in drusy cavities of amygdaloid rocks, and upon metalliferous lodes.

Talc occurs in talcose schist, micaceous schist, chloritic schist, serpentine, gneiss, granular limestone, diorite; upon quartz-dykes in granite, dolomite; upon metalliferous lodes; in drusy cavities, and as a petrifying substance of vegetable remains, in lias-slate and alum-slate.

Meerschaum occurs as a thick bed in the syenite of Pinheiro in Portugal; in serpentine, and as the petrifying substance of *helix*.

Composition.—Delesse and Marignac* have shown that water is an essential constituent of steatite and talc; their results are completely confirmed by Scheerer's analyses of 38 specimens of steatite, talc, and meerschaum from a great number of different localities. In some instances, he found a small amount of carbonic acid in talc, generally a mere trace, which shows how little this mineral is liable to decomposition.

Scheerer† divides these silicates of magnesia into six distinct groups. He states, that steatite is always crystalline, and that this may be ascertained by microscopic experiment with polarized light. It consists of loosely aggregated crystalline particles, whose optic axes are situated in different directions. The composition of steatite, presenting various forms, is perfectly identical.

Meerschaum, when examined by polarized light, generally appears quite amorphous. The four specimens analyzed by Scheerer, all contained carbonic acid, from 0.56 to 2.73 per cent., even those in which there is not any lime. It is uncertain whether this carbonate of magnesia is a product of decomposition, or an original constituent.

Scheerer determined the average composition of steatite, from five analyses of different specimens; that of talc, from four closely corresponding analyses of different specimens. He found that, when some small amounts of other bases are disregarded, both minerals have the same composition, I. The average composition of meerschaum II, was determined in a similar manner.

* Comptes rendus, 1846, xxii, No. 14.

† Poggend. Annal. lxxxiv, 321 et seq.

	I.	II.
Silica	62.61	63.01
Magnesia	32.51	27.78
Water	4.88	9.21
	100 00*	100.00
O. Q. (<i>independent of water</i>)	0.40	0.33

In seven other analyses of talc, the amount of magnesia is as low as 30.07 per cent.; the other bases being present in larger amounts.

Twenty analyses of steatite all indicate the presence of protoxide of iron, to the extent of 6.85 per cent.; three of them indicate the presence of protoxide of manganese, to the extent of 1.4 per cent.; five indicate the presence of alumina, to the extent of 0.84 per cent.; one indicates the presence of soda, with 0.75 per cent. potash; and two indicate the presence of bituminous substance, to the extent of 4.08 per cent.

Thirty analyses of talc, also indicate the presence of protoxide or peroxide of iron, to the extent of 11.7 per cent.; nineteen of them indicate the presence of alumina, to the extent of 5.37 per cent.; one indicates the presence of 2.5 per cent. potash; five indicate the presence of lime, to the extent of 8.1 per cent.; seven indicate the presence of oxide of nickel, to the extent of 0.39 per cent.; and one indicates the presence of 2.5 per cent. carbonic acid.

Seven analyses of villarsite, spadaite, picrosmine, picrophyll, and aphrodite, which are essentially simple silicates of magnesia, indicate the presence of protoxide of iron, one to the extent of 6.9 per cent.; four of them indicate the presence of protoxide of manganese, to the extent of 2.86 per cent.; four indicate the presence of alumina, to the extent of 1.1 per cent.; one indicates the presence of 0.46 per cent. potash; three indicate the presence of lime, to the extent of 0.8 per cent.

Among twelve analyses of meerschaum, seven indicate the presence of protoxide of iron, to the extent of 1.4 per cent; one indicates 12.4 per cent. peroxide of iron; four indicate the presence of alumina, to the extent of 1.4 per cent; three indicate the presence of lime to the extent of 1.01 per cent.; one indicates the

* This corresponds with previous analyses.

presence of 0·52 per cent. potash; five indicate the presence of carbonic acid, to the extent of 2·73 per cent.

Formation.—It is probable that steatite, talc, and meerschaum, as well as the other silicates of magnesia, are in all instances products of the alteration of other minerals, consequently they would rarely, if ever, consist of pure silicate of magnesia, because only the most decomposable silicates would be completely removed from the original minerals.

The great number of pseudomorphs consisting of steatite, show that it may originate from the most diverse minerals. It is also worthy of notice, that the composition of the steatite, with the form of quartz, I, and of that, with the form of bitter-spar, II, approximates very closely to the normal composition.

	I.	II.	III.	IV.
Silica	62·07	62·35	52·28	47·35
Magnesia	31·13	31·32	31·24	24·73
Alumina	0·39	trace	7·33	10·27
Protoxide of iron	1·69	1·34	3·79	7·92
Protoxide of manganese ....	....	....	0·89	2·64
Lime ...	....	....	0·28	...
Water	4·83	4·78	4·04	6·28
	100·11	99·79	99·85	99·19

Under favorable circumstances, therefore, the purest kind of steatite may originate from other minerals.

In an iron mine near Arendal, there is a continuous formation of a mineral—neolite—as a deposit from water, penetrating underground, through rocks consisting of augite, hornblende and talc. The substance of this mineral is of a pale, or dark green, colour, and it sometimes occurs as acicular laminæ; III, is the composition of the pale green, IV, that of the dark green mineral; both analyses are by Th. Scheerer.* Consequently, it is impure talc or steatite, originating probably, in part, from the decomposition of augite and hornblende, in part, by extraction from talcose rocks.

The constant presence, and, sometimes, considerable amount of iron, in steatite and talc, show that in the formation of these minerals from others, the silicates of iron are least readily decomposed. The silicates of alumina appear to be more liable to decomposition, for more than half the analyses of steatite and talc

* Poggend. Annal. lxxi, 285, and lxxxiv, 373.—German edition, ii, 308.

do not indicate the presence of alumina. The silicates of alkalis and of lime appear most liable to decomposition, for these bases are much less frequently present; and steatite never contains any lime.

Villarsite, spadaite, etc., present similar characters, and the sometimes, large amount of manganese, shows that the silicates of this metal are quite as stable as those of protoxide of iron. In the case of meerschaum, there is an exception to the general rule, for more than half the analyses of this mineral do not indicate the presence of iron. It may be inferred, from the amount of carbonic acid that it sometimes contains, that this acid has taken some considerable part in its formation.

Since the silicates of lime, alkalis, and alumina, are decomposed by sulphate of magnesia, or chloride of magnesium,* and silicate of magnesia formed, the conversion of minerals, containing those silicates, into steatite or talc, may be accounted for in this way. Those silicates are constituents of andalusite, chiastolite, felspar,† topaz, wernerite, tourmaline, garnet, augite, hornblende and mica, with the forms of which steatite occurs. Some of these minerals contain silicate of magnesia, and almost all of them contain protosilicate of iron, either in very small or considerable amount. As the persilicate of iron is not decomposed by sulphate of magnesia, or chloride of magnesium,‡ this silicate would not be converted into silicate of magnesia. If carbonic acid were not present, and iron were not removed as carbonate, in consequence of the deoxidizing influence of organic substance, the silicates of iron would remain for the most part undecomposed; and hence their presence in all specimens of steatite and talc.

Silicate of alumina that is so sparingly soluble, is more slowly decomposed than the calcareous and alkaline silicates; and, consequently, it is met with in steatite and talc more abundantly than the latter silicates.

The presence of organic remains in steatite, admits of the conjecture that very large quantities of water must have been brought in contact with the minerals, during their conversion into steatite.

When phenomena of mineral alteration and decomposition, that are of frequent occurrence, can be referred to reactions between the substance of the minerals, and substances that are

* English edition, i, No. 8; and ante, pp. 66, 67 and 69, Nos. 40, 41, and 44.

† See ante, p. 173.

‡ See ante, p. 67, No. 42.

generally present in water, there is great probability really brought about in this way. This is the sulphate of magnesia and chloride of magnesia, which salts occurs in the water of some rivers, spring-water, to a considerable amount.†

The 1·81 sulphate of magnesia in the water of Bonn,‡ would, by decomposition of silicates, form steatite; and since, according to W. L. Horn, 4,687 million cubic feet of water flow past Bonn, the quantity of steatite, that might be formed, would be 5,722,827 pounds, or 32,600 cubic feet, equal to a length and breadth, and one foot thick. In one mile in length and breadth, and one foot thick. Consequently, if the water, percolating rocks, contains sulphate of magnesia as Rhine water, it may be that within long periods, large masses of minerals are formed into steatite. Sea-water contains about 110 times as much of magnesia as Rhine water does.¶ A quantity equal to that annually carried into the sea by the Rhine, therefore, be capable of forming, in one year, a layer 3,450 feet in length and breadth, and 110 feet thick. Examples are sufficient to show the possibility of silicate of magnesia might be formed, which is of the magnitude those actually occurring, even, when the sulphate of magnesia was consumed in the formation of silicates.

Chloride of magnesium is present in the

* English edition, i, 82.—In the water of the Ural, magnesia amounts to 124 parts in 100,000, or 25 per cent. substance. In the water of the Caspian, it amounts to 0·1 per cent. of the dissolved substance.—Mehner.—*Bullet. de l'Académie des Sciences*.—These are the largest amounts of sulphate of magnesia observed in river or sea water.

† English edition, p. 417.—Field states that at the border of Atacama, in Chili, a saline crust, six or eight inches thick, is on the surface; it consists of—

Sulphate of magnesia	....	....	....
" lime	..	....	....
" soda	....	....	....
Chloride of sodium	....	..	....
Water	..	....	..

Quarterly Journal of Chem. Soc. of London, vii, 308.

‡ Ibid. p. 76, No. 4.

§ Poggend Annal. xxxiii, 229.

|| English edition, i, 101, Nos. 7 to 15.

springs,* and sea-water contains a larger amount of this salt than of sulphate of magnesia; so that there is a further source of the production of silicate of magnesia.†

Kersten‡ extracted from a specimen of steatite, a small quantity of chloride of sodium and sulphate of lime. The former salt would be formed by the reaction of silicate of soda with chloride of magnesium, and the latter by the reaction of sulphate of magnesia with silicate of lime. Consequently, it is very probable that water, containing both magnesian salts, has effected the formation of this steatite, from minerals containing those two silicates, and that the chloride of sodium and sulphate of lime had not yet been perfectly extracted. Silicate of soda was still present, for analysis indicated 0·75 per cent. soda, with some potash.

Minerals susceptible of conversion into steatite and talc.—The lime-magnesia augite, and the lime-magnesia hornblende, which are quite free from alumina, or contain only traces of it, and only small amounts of protoxide of iron, are far more susceptible of conversion into steatite and talc, than other minerals. The process of alteration is very simple.§

Andalusite, chiastolite, topaz, felspar, and wernerite do not contain any silicate of magnesia; so that in their conversion into steatite, their silicates are probably decomposed in the manner above described.

The pseudomorphous steatite, after chiastolite, is here and there porous, showing that the silicate of alumina is not entirely replaced by silicate of magnesia. The presence of calc-spar, associated with the steatite originating from wernerite, would appear to indicate that in this alteration carbonic acid was concerned.

Steatite with the form of topaz.|| —Blum¶ describes pseudomorphs of this kind. Topaz, and quartz containing topaz, undergo this alteration, so that pseudomorphous steatite occurs imbedded in steatite. However, the topaz appears to have the greater durability; for unaltered topaz is found between the masses of steatite originating from quartz. The streaks characteristic of topaz are

* English edition, i, 344.

† See German edition, ii, 501. Before I was aware that silicates of lime and alumina were decomposed by sulphate of magnesia and chloride of magnesium, I endeavoured to account for the formation of silicate of magnesia by means of the reaction between silicate of lime and bicarbonate of magnesia. There can be no doubt that silicate of magnesia is formed in this way to some extent.

‡ Journ. für prakt. Chemie. xxxvii, 164.

§ See ante, pp. 322 and 346.

|| See ante, p. 16.

¶ Die Pseudomorphosen, p. 129.

still recognizable upon the pseudomorpha. The alteration progresses from the exterior inwards. Pyknite is subject to a similar alteration. Whether, in the conversion of the silicate of alumina in topaz, and pyknite, into silicate of magnesia, the fluoride of aluminum is removed, or not, must be determined by analysis.

The tourmaline that is converted into steatite is free from magnesia; so that the whole magnesia of the steatite is introduced during the alteration.

Potash-mica and magnesian mica are convertible into steatite;* in the latter case, silicate of magnesia is present in the original mineral.

Steatite, with the form of spinelle.—Fowler† states that this pseudomorph occurs near Newton, New Jersey, together with steatite, with the forms of quartz and wernerite. Blum‡ describes very small octahedrons, consisting of steatite, imbedded in steatite, and which, probably, originate from actinote. Near Daulta la Toja, in the Tyrol, very fine octahedrons, from two lines to an inch in diameter, are found consisting of steatite, evidently originating from pleonaste.

Spinelle consists, essentially, of alumina and magnesia. Among eight analyses, six indicate the presence of protoxide of iron, to the extent of 4.26 per cent.; two indicate the presence of lime, to the extent of 7.4 or 10.6 per cent. Among nine analyses of pleonaste, eight indicate the presence of protoxide of iron, to the extent of 23.5 per cent. With one exception, all the analyses of spinelle, indicate the presence of silica, to the extent of 0.96 or 5.6 per cent.

The following analyses illustrate the decomposition of spinelle and pleonaste :—

	I.	II.	III.	IV.
Silica	31.10	37.5	1.23	....
Alumina	17.50	15.7	66.89	71.32
Peroxide of iron	2.76	4.6	(FeO 8.07)	....
Oxide of manganese ....	....	1.7	....	....
Magnesia	29.69	25.8	23.61	28.68
Lime	5.56	8.7	....	....
Water	13.67	6.0	....	....
	100.28	100.0	100.00	99.80

* See ante, p. 405.
† Silliman's American Journ. xxi, 320.
‡ Die Pseudomorphosen, p. 114.

I. A pseudomorphous steatitic mineral, after pleonaste, from Monzoniberg, in the Fassathal	} Analyzed by Marignac.*
II. The same mineral	
III. Pleonaste, from Monzoniberg	Stadler.† Abich.‡

This mineral was mixed with carbonate of lime, in small cracks, which extended, in many instances, through the entire crystal; the carbonate of lime was separable by hydrochloric acid.

When to the silica, in I, is added the equivalent of magnesia, to form with it steatite; and to the alumina, the equivalent of magnesia to form spinelle, in accordance with the theoretical composition of that mineral, IV; it would appear that there is 49·67 per cent. hydrated steatite, with 24·53 per cent. spinelle, and 6·51 per cent. overplus of magnesia. When a similar calculation is made for II, it appears to consist of 56·97 per cent. steatite, and 22·01 per cent. spinelle, with 0·02 per cent. overplus of magnesia.

It follows from these analyses, that :—

1. In the mineral represented by II, the decomposition of the spinelle is further advanced than in that represented by I.

2. As there is an overplus of magnesia in I, the amount of silica introduced, was insufficient for the perfect conversion of the mineral into steatite.

3. In II this was not the case; however, the correspondence between the results of analysis and calculation, must be regarded as merely accidental, since it was not determined whether the oxides of iron and manganese were in the state of aluminates or of silicates.

As the unaltered, or slightly altered pleonaste, represented by III, contained an admixture of carbonate of lime, it is highly probable that the decomposed pleonaste, represented by I and II, also contained carbonate of lime.

In these analyses no carbonic acid is indicated; but, probably, Marignac and Stadler did not treat these substances with hydrochloric acid, but merely estimated the loss by ignition. It is evident that this deficiency is not altogether owing to the presence of water, for the water required by the steatite, is, in I, 2·42, and in II, 2·92; and as pleonaste and spinelle are anhydrous, it does

* Archiv phys. nat. vi, 302.

† Jahresbericht von Liebig, etc., 1847-8, p. 1197.

‡ Poggend. Annal. xxiii, 328.

not appear with what substance the excess of water could have been combined.

The lime in the calcareous spinelle, from Franklin and Amity, analyzed by Thomson, was, probably, in the state of carbonate; in the analysis of the spinelle from the latter locality, carbonic acid is indicated to the amount of 2·8 per cent. The occurrence of this spinelle, in granular limestone, leaves little doubt as to there being an admixture of carbonate of lime. Lime would appear, therefore, never to be an essential constituent of spinelle or pleonaste. Consequently, the carbonate of lime with which these minerals are so frequently mixed, would not be a product of decomposition, but infiltrated.

A pseudomorph from Sommersville, New York, consisting of spinelle and mica, contained, according to Johnson,* after deducting the silica :—

	I.	II.
Alumina	23·87	17·65
Magnesia	43·84	38·59
Water	26·45	43·76
Carbonic acid	5·83	3·92

If this analysis is correct, the carbonic acid must have been combined with magnesia. The composition of völknerite is analogous to that of this mass, according to Hermann's† analysis II. Here, also, the carbonic acid appears to be combined with magnesia; but, in other respects, the composition of both minerals, independently of the large amount of water, deviates so much from that of spinelle, that they can scarcely be regarded as altered spinelle.

According to H. Rose, silica does not enter into the composition of spinelle, for, when fused with bisulphate of potash, it is perfectly soluble in water. He did not find any silica in two analyses of chlorospinelle. Even if silica was wanting in only one specimen of spinelle, it might be conjectured that the other varieties, which contain silica, were already undergoing conversion into steatite. The pleonaste represented by III was corroded at the surface; and this, is probably connected with the presence of silica. It would appear, therefore, that spinelle and pleonaste consist merely of aluminates of magnesia and protoxide of iron.

* American Journ. xii, 361.

† Journ. für prakt. Chemie. xl, 12.

It has already been shown* that aluminate of magnesia is decomposed by silicate of soda; so that water, containing alkaline silicates, may effect the decomposition of spinelle. But, as this decomposition does not consist in a mere exchange of constituents, aluminate of soda being produced only to a small amount, the conversion of spinelle into steatite, can be complete, only, when it is continuously brought in contact with water containing alkaline silicate, which would gradually extract the alumina.

The analyses, above quoted, of pseudomorphous steatite after pleonaste, indicate the presence of considerable amounts of alumina and other bases; so that the alteration is far from being complete. Further analyses must determine whether there are other pseudomorphs, from which the alumina has been entirely removed.

Pleonaste appears to be also susceptible of conversion into mica. Abich† states that the pleonaste from the Ural, analyzed by him, was mixed throughout with laminæ of mica. The conversion of this mineral into steatite, renders the conversion into mica probable, especially if the mica observed was magnesian mica.‡

Steatite, with the form of calc-spar.—Nauck§ describes pseudomorphs of this kind. The interior consists of small rhombohedrons of bitter-spar. He considers them as secondary pseudomorphs; the calc-spar having been first converted into bitter-spar, and that into steatite.

Steatite, with the form of bitter spar.—Blum|| describes a mineral from Marlborough, in North America, in which he traced the conversion of bitter-spar into steatite. The alteration commenced at the surface, and progressed inwards. The bitter-spar first becomes turbid and dull, of a pale, dirty-green colour; then blackish-green, black, and yellowish-white, a crust of steatite being formed; and, lastly, the whole mass of the crystal is converted into steatite.

The description given of these pseudomorphs is indicative rather of conversion than displacement. As bicarbonate of magnesia is decomposed by silicate of potash,¶ it might be supposed that water, containing silicate of potash and carbonic acid, has effected the alteration. But as bitter-spar contains 22·09 per

* See ante, p. 78, No. 52.

† Loc. cit. p. 327.

‡ It is to be regretted that the mica was not analyzed.

§ Poggend. Annal. lxxv, 129 et seq.

|| Die Pseudomorphosen, p. 112.

¶ See ante, p. 69, No. 46.

cent. magnesia, the steatite formed in this way would amount to only 73 per cent. of the bitter spar, by volume, which does not agree with the fact, that the whole of the crystals consist of steatite without cavities. Whatever other process might give rise to this alteration, there would still be a reduction of volume to the extent of 27 per cent., unless magnesia were introduced; and, consequently, the pseudomorphs would appear porous. Therefore, it is probable, that these pseudomorphs have been formed by displacement.*

Steatite, with the form of quartz, can, in like manner, be regarded only as a displacement pseudomorph.† When, as at Göpfersgrün, totally different minerals—quartz, bitter-spar, and dolomite—have been converted into steatite, and steatite has also been deposited in cavities, it may be inferred that the pseudomorphic process was, in all cases, the same, or was, at least, dependent upon the same conditions, more particularly since the formation of neolite shows that silicate of magnesia may be deposited from water. It is quite possible that water, containing silicate of magnesia in solution, might displace the substance of many minerals, and deposit steatite in its place.

However, there are other circumstances which admit of the inference that different processes of alteration have taken place in the same locality. At Monzoniberg, steatite occurs with the forms of pleonaste, and of mica. Those minerals differ so much in composition, that it is vain to seek for any process of alteration that may be considered as common to both. The only alternative appears to be the opinion, that certain substances, present in the water have effected the alteration of pleonaste, while others have effected the alteration of the mica, or that these minerals underwent alteration at different times, in consequence of change in the substances present in the water. Some specimens of “steatite upon dolomite, from Thiersheim, near Göpfersgrün,” in the Berlin collection of minerals, show distinctly that the steatite mass was deposited before the bitter-spar crystals were altered. It may be, also, that the steatite, with the forms of spinelle, quartz, wernerite, and hornblende, in the above-mentioned pseudomorphs, was formed by successive processes of alteration, from different minerals.

Steatite is also said to occur with the form of staurolite.‡

* English edition, i, 19.

† See Chapter xlii.

‡ Die Pseudomorphosen.

Breithaupt* describes a displacement pseudomorph of steatite after baryta-spar. The displacement is not always complete; and, in some instances, there is a nucleus of baryta-spar in the pseudomorphs.

Alteration pseudomorphs, with the form of felspar,† couze-ranite, chiasolite, cyanite, and garnet,‡ have already been spoken of.

As talc and steatite have the same composition, it may be supposed, that all minerals, which are susceptible of conversion into steatite, would also be susceptible of conversion into talc. The remarks already made as to the alteration in the case of steatite pseudomorphs, will be equally applicable to the formation of talc pseudomorphs.

Blum§ describes a pseudomorph from Kreuzjoch, in the Zillerthal, consisting of talc, with the form of magnesite-spar. The talc appears as if intruded in the direction of the planes of cleavage; some magnesite still remains. This talc consists, according to the analysis by H. Bauer, of—

Silica	....	....	52.16
Magnesia	....	....	28.47
Protoxide of iron	....	....	17.62
			<hr/>
			98.25

This pseudomorph does not possess the peculiar composition of talc. The amount of bases is too large; that of silica too small. However, as the pseudomorph consists of very thin laminæ and pale greenish-white fibrous particles, it would appear to consist of two different substances. Perhaps the fibrous particles are analogous to chrysotile. This mineral appears as a displacement pseudomorph.

* Nachtrag, 2, p. 135.

† See ante, p. 173.

‡ See ante, pp. 272, 294.

§ Nachtrag, 2, p. 47.

CHAPTER XLII.

QUARTZ, AND OTHER SILICEOUS MINERALS.*

NEXT in order to the compound silicates, I proceed with the consideration of two oxides, quartz, and magnetic iron-ore, because they are both very frequent constituents of rocks. Their consideration in this place is the more appropriate, because, as will be shown subsequently, they are both products of alteration.

Silica occurs in two different states; the one modification is insoluble in water, acids, and most liquids, except hydrofluoric acid, a substance that does not appear ever to have been concerned in the phenomena of mineral formation or alteration. Rock-crystal, quartz, &c. furnish examples of this kind of silica.

The other modification of silica is soluble in water and acids, to such an extent, that its solubility may be determined. This kind of silica is present in all water, and also occurs in a solid state, as a product of the decomposition of silicates.

The largest amount of silica that I have found in the water of cold springs is $\frac{1}{10000}$. According to Fuchs,† moist gelatinous silica requires for solution 7,700 parts of water, 11,000 parts of cold hydrochloric acid, and 5,500 parts of boiling hydrochloric acid.

After digesting a piece of float-stone with distilled water, for 12 hours, there remained, upon the evaporation of the water, $\frac{0.16}{10000}$ of residue, colored by carbonaceous substance, and containing 0.04 silica. It follows, from the analyses of thirty-one kinds of mineral water, that the amount of silica is greater in direct proportion to the amount of carbonate of soda present. In the water that contained the largest amounts of these substances I found 17.5 carbonate of soda and 0.68 silica in 10,000 parts of water. When this amount of carbonate of soda was added to the water with which the float-stone was digested, the silica dissolved amounted to 0.2 parts, or five times as much as that dissolved by water alone. Therefore, it is probable that the carbonate of soda in the water of cold springs facilitates the solution of silica.

It is certain that the solvent action exercised upon the silicates,

* It will be advantageous to describe the characters of siliceous minerals before enumerating the conditions of their occurrence, so that the mode of origin may be more evident.

† Erdmann's Journ. für prakt. Chemie, lvii, 6.

by the water of hot springs, is much greater than that exercised by the water of cold or tepid springs. From a theoretical point of view it might be conjectured that at some depth below the surface the temperature of the water of boiling springs must be above 212°F. ; and the observations made in July, 1846, by Descloizeaux and Bunsen* have confirmed this conjecture. They found that at the bottom of the Geyser, at a depth of 22 meters, the temperature before an eruption was from $261^{\circ}\cdot 5\text{ F.}$ to $251^{\circ}\cdot 5\text{ F.}$; and during an eruption it was $255^{\circ}\cdot 5\text{ F.}$ In the Stork spring, in Iceland, they found, at a depth of 13·55 meters, a temperature from $234^{\circ}\cdot 5\text{ F.}$ to 238° F. It is evident that at such a temperature, and under a pressure of two or three atmospheres, the solvent action exercised upon the silicates must be much increased.

The source of the silica so abundantly present in solution in the water of the Geysers, has been pointed out by the observations made by Eug. Robert,† at the small mountain of Laugarfiall, near the great Geyser. He found at this place, distinct vestiges of a former hot spring of considerable extent. He separated from the basin, out of which it had risen, some fragments of a substance analogous to kaolin, while at all other parts the rock had scarcely experienced any alteration at the surface. According to de Chancourtois, the unaltered phonolite of Laugarfiall contains 72·3 per cent. silica, while the altered rock contains only 65·8 per cent. Robert infers, therefore, that the silica in the water of the hot springs in Iceland, is derived from the phonolite, basanite, and dolerite by decomposition.

Kersten‡ found that by acting upon some siliceous substances and three specimens of labrador,§ with hydrochloric acid, the silica was obtained sometimes as a powder, and sometimes gelatinous. According to v. Kobell,|| chonicrite presents the same character. H. Rose states that the silica of all silicates that are not completely, or readily, decomposed by hydrochloric acid, separates as a powder; but that it separates in a gelatinous state from minerals, which are readily and completely decomposed by hydrochloric acid, as, for instance, zeolites.¶

The different characters of unaltered and weathered siliceous magnesite have already been pointed out.** Generally speaking,

* Comptes rendus, xxiii, 934.

† Comptes rendus, 1841, No. 19, p. 932.

‡ Schweigger's Journ. lxvi, 38.

§ See ante. p. 206.

|| Journ. für prakt. Chemie. ii, 51.

¶ See ante, p. 137.

** See ante, p. 83.

silicates are more readily decomposed by acids, the more alteration they have undergone by weathering, so that from a mineral, from which, when unaltered, silica is separated as a powder, gelatinous silica separates when it is completely decomposed.

If the silica dissolved in water retains that pulverulent or gelatinous condition which it presents when separated from silicates by the action of acids, it might be separated from water in either state; and in this way the various siliceous substances formed by deposition from water might be accounted for.

Even in compact quartz, the silica appears to be in different states. Thus the large masses of rock which project from the serpentine at the summit of the Steinberg, near Jordansmühle, consist of two different modifications of compact quartz; one is greyish, or yellowish-white, almost opaque; the other greyish, semi-transparent, with vitreous lustre.*

A dilute water solution of silicate of soda that had been standing in a well-closed vessel for a year and a half in my laboratory, was found to have deposited a gelatinous substance, consisting of 97·6 per cent. silica, and 2·4 per cent. soda. This separation of silica without the action of carbonic acid,† or any other such cause, shows that the formation of quartzose substances may have taken place by the separation of silica from silicates dissolved in water. Hence it is explicable that silica is deposited as quartz upon the sides of fissures, or of vesicular cavities, by water containing alkaline silicates, originating from felspar by decomposition. If by the gradual evaporation of the water a solution of silicate of soda, similar to that above mentioned, is formed, silica would be separated in the course of time, and give rise to the formation of quartz dykes, and veins, or the siliceous substances met with in the cavities of amygdaloid rocks.

Klaproth found in flint 0·5 per cent. lime, 0·25 per cent. alumina, and 0·25 peroxide of iron. Berzelius found in the same mineral 0·134 per cent. potash, 0·113 per cent. lime. Minute amounts of potash and soda were found by Heintz in carnelian and amethyst, and by Kersten in the hornstone of Marienbad. The presence of these substances indicate that the minerals had been formed from silicates. The water running down the face of the rock would remove the alkali, or, probably, basic silicate after the deposition of silica.

* Verhandlungen der Leop. Carol. Acad. der Naturforscher, xiv, Abthl. 2, p. 558.

† The influence of carbonic acid has already been treated of, see ante, p. 57.

Ebelmen's experiments with silicic ether likewise indicate that there is a connection between the state in which silica is eliminated, and the state in which it exists in combination.

The numerous instances in which substances pass from one isomeric state to another, under the influence of apparently unimportant circumstances, render it probable that silica may also present this character of easy transition from the amorphous to the crystalline state.

When a silicate is decomposed by fusion with an alkaline carbonate, and the resulting mass extracted by water, the solution contains, besides alkaline carbonate, some silicate of the alkali and alkaline aluminate. Carbonate of ammonia precipitates silica and alumina. When, therefore, water contains in solution, besides silica, nitrogenous organic substance, which putrifies, the silica would be precipitated by the carbonate of ammonia formed. In this way the frequent deposition of silica effected by organic substance may be accounted for.

Rock crystal and opal appear as the final members of the series of siliceous minerals; the former as perfectly crystallized silica, the latter as perfectly amorphous silica. If the presence of water in opal is the reason of its being amorphous, it might be conjectured that the crystallization of other kinds of amorphous silica would be prevented similarly.

According to the experiments of a great number of chemists, chalcedony loses by ignition from 0.4 to 2.5 per cent., becoming at the same time milk-white, translucent, and very brittle; iron-flint loses from 0.73 to 1.0 per cent.; hornstone, from 0.5 to 2 per cent, becoming white; haytorite loses 0.5 per cent.; rock crystal, from 0.05 to 0.79 per cent.; prasem, 0.25 per cent.; quartz 1.0 per cent. Fibrous quartz and rose-quartz do not experience any loss by ignition; the brownish colour of the former becomes pale slate-grey, the red colour of the latter passes into milk-white. Smoke-topaz loses its colour when ignited, but experiences a loss of only 0.01 per cent. Carnelian, that is colored by oxide of iron, loses 0.391 per cent. water, and 0.003 carbon. Amethyst gives 0.003 per cent. carbon, loses from 0.16 to 0.3 per cent. by ignition, and becomes colorless. Flint gives from 0.037 to 0.27 per cent. carbonic acid, and from 1.1 to 1.3 per cent. water. The colour of those siliceous substances which are decolorized by ignition is unquestionably owing to the presence of organic substance.

The crystallized siliceous substances do not differ from those that are amorphous in the amount of loss by ignition; so that the

small amount of water in the latter cannot be the reason why they are not crystalline. This character may, with greater probability, be attributed to the bases present—peroxide of iron, oxide of manganese, alumina—amounting to from 0·5 to 1·5 per cent., while in rock crystal and amethyst they amount to only 0·005 per cent.; for there are many instances of crystallization being hindered by small admixtures of extraneous substances.

From a great number of experiments made by Schaffgotsch,* it follows that the specific gravity

				Mean
of quartz crystal and powder varies from	2·647	to	2·661	.... 2·653
that of pure silica, not ignited and ignited, from	2·190	to	2·220	.... 2·200
that of opaline minerals, not ignited and ignited, from	1·340	to	2·300	

Ignited opal and pure silica are, therefore, one-sixth lighter than quartz. It is singular that the specific gravity of opal, that has been rendered anhydrous by ignition, is less than that of pure silica prepared artificially; but by prolonged ignition the density increases, and finally equals that of artificially prepared silica.

These facts also indicate that the silica of opal is in a different state from that in crystallized quartz; and that the amorphous character is owing to this, and not to the presence of water. Everything tends to strengthen the opinion that silica is capable of assuming not only two isomeric states, but perhaps several.

According to Wolff,† the density of both rose-quartz and smoke-topaz appears to be increased by ignition.

		Specific gravity.	
		Before ignition.	After ignition.
Rose-quartz	....	2·6569	.... 2·6578
Smoke-topaz	....	2·6563	.... 2·6574

This increase is, however, so minute that further experiments are desirable.

Opal may be compared to a solidified mass of gelatinous silica, in which, according to the extent of dessication, the amount of water may vary much. The Saxon hydrophane is said to occur, in the mine, so soft that it receives the impression of a hard substance.‡ It contains organic substance, and, according to

* Poggend. Annal. lxxviii, 147.

† Loc. cit.

‡ Klaproth.—Beiträge, ii, 155. —Glocker also mentions several instances of this kind, loc. cit. p. 566. He obtained out of chrysoprase a soft, tenacious, moist, opaline substance that gradually hardened by exposure to the air, and then resembled exactly white opaque cacholong.

Ehenberg, organisms, so that when heated it evolves empyreumatic water. According to Damour,* noble-opal and semi-opal also evolve empyreumatic ammoniacal water, and the band-opal is full of infusoria. The amount of water varies from 1·0 to 10·0 per cent.; it appears to be united to the silica with unequal degrees of chemical affinity. Thus v. Kobell found that an iridescent opal lost, by slight ignition, 7·5 per cent., and, by intense ignition, 3·44 per cent. more. The hyalite of Waltsch lost 4 per cent. water only by intense ignition; the glass-opal lost 5·3 per cent. at a moderate heat, and 3·59 per cent. more at a higher temperature.† Schaffgotsch found in this hyalite, which consisted of 95·5 silica, 0·8 peroxide of iron; and 0·2 lime from 2·9 to 3·1 per cent. water. It would appear, therefore, that opal is not a definite hydrate. Berzelius was unable to prepare a definite compound of silica and water.

Opal sometimes contains besides magnesia minute amounts of alkalis. This is also the case with flint, cacholong, and carnelian; the latter contains also minute amounts of peroxide of iron and magnesia; amethyst also contains lime and magnesia.‡

The occurrence of opal in fissures, shows that it has been deposited from water. The presence of infusoria, shows that some kinds of opal, at least, have been formed by organic agency. The opaline substance, with the form of augite, already mentioned,§ shows, that it may be formed by the alteration of other minerals. Besides these modes of occurrence, opal is frequently the petrifying substance of plant remains, especially wood. Wood-opal of this kind occurs in the brown-coal sandstone at Quegstein, in the Siebengebirge, and, also, at Obercassel. Fragments of trunks, and branches of trees, presenting the organic structure in a very perfect manner, consist, entirely, of a yellowish-white, opaline mass. The bark, only, is wanting; and, instead of it, there is, at places, a thin coating of reniform hyalite, which is sometimes met with in cavities within the silicified wood. The wood opal of Tokay, in Hungary, still presents, at the interior, wood which is but little altered.||

According to R. Brandes,¶ the following is the composition of the wood-opal of Quegstein, I, and of Obercassel, II:—

* Ann. des Mines. xvii, 202.

† Charakteristik, i, 253.

‡ German edition, i, 828.

§ See ante, ii, 324.

|| Blum.—Nachtrag, p. 197.

¶ Nöggerath.—Das Gebirge in Rheinland-Westphalen.

						I.	II.
Silica	...	...	...	...	...	86.00	93.00
Alumina	...	...	...	...	...	0.50	0.13
Peroxide of iron	...	...	...	...	...	3.50	0.37
Sulphuric acid	...	...	...	...	...	0.17	trace
Carbonic acid	...	...	...	...	...	0.03	...
Water	...	...	...	...	...	9.97	6.13
						100.17	99.63

It appears from these analyses, that the substance of the wood has been replaced, almost entirely, by silica; and that ligneous fibre may be removed by the action of water, although regarded as perfectly insoluble.

Opal differs from quartz, besides in containing water, by the much lower specific gravity, inferior degree of hardness, simple refraction, and in its chemical characters.

Fuchs* found that powdered opal combines with lime, in the wet way, and yields a hard mass under water, a character that quartz does not present. Quartz, powdered, dissolves slowly, and with difficulty, in boiling solution of potash; powdered opal dissolves in a few minutes, and even lumps of opal dissolve when the boiling is continued. At the ordinary temperature, quartz is not at all acted upon by potash; but opal, either in lumps or powder, is gradually dissolved. However, all kinds do not present the same character in this respect; some do not dissolve within from two to five months; hyalite dissolves slowest. This difference does not depend upon the amount of water in opal, for its solubility in potash is not affected by the expulsion of the water by heat. This is also the case with amorphous silica, prepared artificially.

Kobell† found that amorphous silica, as, for instance, polished plates of opal, heliotrope, carnelian, flint, wood-stone, and jasper, was always more considerably acted upon by hydrofluoric acid, than crystallized silica; as, for instance, plates of rock crystal and amethyst. He considers this analogous to the dissimilar behaviour of amorphous and crystallized silica with potash.

I have found that several specimens of semi-opal from Hungary and the Siebengebirge, when digested with hydrochloric acid, are,

* Jahrbuch der Chemie, und Physik. vii, 419.

† Journ. für prakt. Chemie, xxxvi, 307.

to a great extent, deprived of the bases present, silica remaining as a rough powder ; several days' digestion was, however, requisite.*

Opal is not always homogeneous ; and, not unfrequently, contains fine particles of quartz. Klaproth† observed, in analyzing fire-opal, that each granule contained a white, apparently siliceous mineral, around which the small, conchoidal projections of the mineral were arranged in a stellar manner. Fuchs found that a milk-white opal, that was digested for half a-year in caustic potash, left a porous quartz skeleton, which fell to powder when shaken. He considers it probable, that the iridescence of noble opal is owing to the presence of minute particles of quartz, arranged in such a manner as to refract light differently. This is more probable, since no transparent opal is iridescent, but only such as is translucent ; and, probably, rendered so by admixture of quartz.

Breithaupt mentions some observations which appear to indicate that quartz may be formed from opal, and that chrysoprase also presents indications of transition into crystallized quartz.‡ Damour§ found that an opal, which contained 10·1 per cent. water, had, after lying four months in dry air, lost 4·05 per cent. But it must be decided, by further experiment, whether the whole of the water may be removed from opal in this way.

Decomposition of opal.

	I.	
	<i>a.</i>	<i>b.</i>
Silica	83·73	73·45
Peroxide of iron	3·58	9·95
Lime	1·57	1·21
Magnesia ...	0·67	2·13
Water ...	11·46	12·89
	101·01	99·63

I, *a.* Fresh, lustrous opal, from Meronitz.

b. Weathered, dull variety ; analyzed by Wertheim.||

If the mineral represented by *b*, originated from that represented by *a*, silica and lime have been eliminated, and peroxide of iron, magnesia, and water introduced.

* German edition, ii, 1232 et seq.
† Beiträge, iv, 157.
‡ German edition, ii, 1234 et seq.
§ Bull. de la soc. géol. Sér. 2, v, 157.
|| Rammelsberg.—Handwörterbuch, Suppl. p. 107.

In the trachyte of Rosenau, in the Siebengebirge, a brown, lustrous kind of opal—opal-jasper, II, *a*, occurs in dykes, and, generally, surrounded by a sharply-defined, pale-yellow, dull crust, II, *b*, which may be scratched by the former, and appears to be a product of its alteration.* Both minerals lose water at 212° F. ; and, when ignited, evolve more water, and products of the decomposition of organic substance. Another kind of yellow opal, V, also occurs, resembling that represented by *b*, in colour, but quite as lustrous as that represented by *a*. Analysis showed that the former contain more oxide of iron than the latter, and, consequently, several pieces were analyzed to ascertain whether this difference was general. The analytical results are reduced, to refer to ignited opal.

	II.		III.		IV.		V.
	<i>a.</i>	<i>b.</i>	<i>a.</i>	<i>b.</i>	<i>a.</i>	<i>b.</i>	
Silica	96.12	94.49	96.05	94.67	94.50	94.42	95.55
Alumina	0.50	0.60	3.49	5.26	3.38	5.31	4.37
Peroxide of iron ...	3.30	4.85					
Lime ...	trace	trace					
Magnesia	0.08	0.06	0.04	0.02			
Potash	not estimated		0.06	0.05			
	100.00	100.00	100.00	100.00			99.92

II *a*, III *a*, IV *a*. Brown, lustrous opal, constituting dykes in the Rosenau trachyte.

II *b*, III *b*, IV *b*. Pale yellow, dull crust, surrounding the opal.

The loss, by ignition, amounted to from 5.11 to 5.60 per cent. of the mineral represented by *a*, and from 6.77 to 5.95 of that represented by *b*.

V. Yellow opal, from the same locality.

Although in the analyses III and IV the alumina was not separated from the oxide of iron, still, as the former is always present in less proportion than the latter, it appears that the amount of iron in the weathered opal is always greater than in

* The conversion of brown opal into the pale yellow substance of the crusts, by the introduction of peroxide of iron is very remarkable ; and the fact that by ignition the former becomes brownish-red, while the latter becomes only reddish-brown, is still more remarkable. It does not appear why the yellow crust which contains more peroxide of iron than the opal should not acquire a darker colour than it by ignition. The specific gravity of the brown opal is 2.142 ; that of the yellow crust 2.168, the increase undoubtedly being due to the increased amount of iron.

that which is unaltered. Some small amount of silica has, therefore, been removed, and peroxide of iron* and water introduced, so that the alteration is essentially the same as in the case of the opal represented by I, *a* and *b*. The opal represented by V does not appear to be altogether altered, but in a state of transition into the mineral represented by *b*.

As the opal at Rosenau is, undoubtedly, a product of the decomposition of trachyte, and has been transferred into the fissures by means of water; and, further, since the brown-coal sandstone, in which the wood-opal† is imbedded, is covered by trachytic conglomerate, it is probable that the silica in this mineral, also, originates from the trachytic mass.

Above Quegstein there is a spring, the water of which flows for some distance along the surface, then sinks into fissures in the brown-coal sandstone, and appears again at a lower point. As it seemed that this water might have furnished the silica for the formation of opal, I made an analysis of it, and found that it contained, in 10,000 parts:—

Silica	....	....	....	0.262
Carbonate of lime	....	....	....	0.898
„	magnesia	....	....	0.044
„	protoxide of iron	....	....	trace
Alkaline chlorides	....	....	....	0.122
				<hr/>
				1.326

When the water was evaporated nearly to dryness, an alkaline reaction became perceptible; and bichloride of platinum indicated the presence of a trace of potash. I was unable to ascertain whether soda was also present. The amount of water yielded by this spring is, in

24 hours,	5,142 cubic feet, containing	8.9 pounds of silica.
1 year,	1,876,830 „ „	3245.0 „ „

This water, therefore, contains a sufficient amount of silica for the formation of wood-opal and brown-coal sandstone, as well as for cementing the quartz pebbles that constitute some beds of this sandstone. The presence, in this rock, of quartz pebbles, and of fragments of tree-trunks and roots, converted into wood-opal, indicates that it is a tertiary deposit; and that the water,

* The brownish-red opal of Telkebanya contains as much as 47.0 per cent. peroxide of iron according to Klaproth.

† See ante, p. 459.

flowing from the trachyte and trachytic conglomerates, contained silica.

Glocker* states, that in Silesia, hyalite occurs most abundantly at the edges of the serpentine and quartz rock, and with the most diverse forms. This is, no doubt, owing to the facility with which the water evaporates while flowing slowly over the face of the rock. Hyalite never occurs in fresh serpentine, or at any considerable depth. At the Steinberg, it is situated upon plates of yellow and brown opal; sometimes there is a perfect transition of one mineral into the other, and sometimes layers of hyalite and opal alternate. Among the more considerably decomposed masses of serpentine with overlying hyalite, Glocker found several that were covered with small, black lichens, while the surface of the hyalite was free from them. Underneath the transparent hyalite crust, the same black lichens could be distinctly recognized. He is of opinion that the hyalite upon the quartz rock, near Jordansmühle, has been formed within six or eight years. Zipfer † states, that at Bohunitz it has been formed within one year.

It is more probable that the lichens have facilitated the formation of hyalite by retaining the siliceous water, rather than by means of any chemical affinity of the organic substance for silica. In the latter case, the lichens would have effected the precipitation of silica only so long as they were not quite covered by hyalite.

Fuchs ‡ considers chalcedony to be a mixture of quartz and opal, because caustic potash extracts silica from it at the ordinary temperature, and converts it into cacholong. When finely powdered chalcedony was digested for half an-hour, with dilute boiling caustic potash, 8·9 per cent. silica was dissolved, that must have been mostly opal. Quartz treated in the same way was but very slightly dissolved. Fuchs found that a smooth fragment of chalcedony that appeared quite homogeneous, presented, after having been immersed for a year in moderately strong caustic potash, a number of parallel streaks, some white and almost opaque, the others grey and translucent. The potash had dissolved 3·9 per cent. silica. He infers hence that this chalcedony consisted of alternate layers, with unequal amounts of opal. At Oesteroe the chalcedony is traversed by layers of common opal. He consequently divides compact quartz into two kinds; the one containing

* Loc. cit. p. 545.—See also L. Müller.—Jahrb. f. Min. etc. 1850, p. 419.

† Versuch eines Topograph. Mineral. Handb. von Ungarn. 1817, p. 40.

‡ Poggend. Annal. xxxi, 577.

opal, and including, besides chalcedony and analogous substances, flint; the other, free from opal, and including cacholong, hornstone, siliceous slate, &c. Opal also appears as the cementing substance of many sandstones.

The following experiments gave the same result. A piece of chalcedony was broken in two, and one half intensely ignited, by which treatment it lost 0·54 per cent. Both halves were powdered and digested for half an hour with boiling caustic potash; of that which had not been ignited 2·984 per cent. was dissolved; of that which had been ignited 2·177 was dissolved; so that the silica dissolved in the former case amounted to 0·807 per cent. more than in the latter case. This agrees tolerably with Fuch's opinion; for it might be supposed that by ignition and elimination of water the solubility of the silica would be somewhat reduced.

If the portion extracted by caustic potash is really opal, chalcedony would always contain some water proportionate to the amount of opal. It may, therefore, be conjectured that the admixture of amorphous opal prevents the crystallization of chalcedony.

Hydrofluoric acid has the same action upon chalcedony as caustic potash has. v. Kobell found that when a polished plate of chalcedony was submitted to the action of this acid markings became apparent, and the streaks of quartz appeared prominent, while the amorphous silica had been removed to some depth.

The occurrence of chalcedony with globular, reniform, and stalactitic forms indicates its amorphous character. The descriptions of crystallized chalcedony given in some mineralogical works must be ascribed to inaccurate observation.

According to Fuchs, flint is also a mixture of quartz and opal. Several thin splinters, digested for ten minutes in concentrated caustic potash, became white and opaque, like hornstone, but did not lose more than 1·7 per cent. The silica dissolved from powdered flint by digesting it for half an hour with boiling dilute caustic potash, amounted to 7·5 per cent. Fuchs infers hence that flint really contains opal, though rather less than chalcedony.

Nearly fifty years since Hacquet* published some interesting remarks on the formation of flint. He showed that there is no doubt it originates from the chalk, in which he found 7 per cent. silica, and that it is of very recent formation. Near Podgorze, in the neighbourhood of Cracow, petrified roots of beech were found

* Gehlen's Journ. für Chemie, und Phys. i, 89, et seq.

in the midst of large lumps of flint; one lump of flint contained very small petrified chips of wood.*

Hacquet found that in the brownish-black flint, there are generally rather irregular cubical masses, consisting sometimes of pure laminar calc-spar. One piece that was traversed by veins of reddish-brown jasper, contained thirteen masses of this kind. After extracting the carbonate of lime from five of them, Hacquet obtained residua, consisting of from 89 to 97 per cent. silica, 0·25 to 4·25 per cent. lime, besides alumina and peroxide of iron.

The presence of these calcareous masses in flint is interesting. Other substances also are imbedded in flint. Thus, gypsum-spar occurs upon the faces of fissures in flint from the neighbourhood of Madrid; and celestine, in a specimen of flint, from France.†

The chalk beds of southern Europe do not contain any flint, or but very little; those of northern Europe contain a considerable amount, the masses being arranged in very regular horizontal layers, frequently only from one to six feet apart. On the contrary, the chalk beds of northern Europe do not contain infusorial-marl which is so abundant in Sicily, Oran, and Greece. A comparison of the southern infusorial-marl and the northern flint beds is very much required. Ehrenberg‡ is of opinion that this relation would account for the formation of flint. The deficiency of siliceous infusoria hitherto observed in the chalk has been shown not to be general, for in the flint of the Jura limestone of Cracow, he found well preserved peculiar *polythalamia*, and remains of sponges or *tethya* and *polythalamia*, in the flint from the gault of Cambridgeshire.

Bronn§ is of opinion that the production of morpholites did not commence until after the rocks in which they were imbedded had been formed; and in that case it may take place at the present time, as Ehrenberg supposes. At the conclusion of this chapter, in treating of silicification, chemical evidence of the most probable mode of formation of flint will be brought forward.

Minerals with the form of quartz.—The conversion of quartz into other minerals cannot take place either by loss of constituents or by interchange; it is just possible that minerals may be formed from quartz by the introduction of bases. But the bases in water—alkalies, earths, protoxide of iron, &c.—are combined with carbonic or sulphuric acids, chlorine, &c., and in that state are incapable of displacing silica in the wet way at the ordinary temperature.

* These chips can only have been made by squirrels and similar animals which are frequent in these woods.

† Sillem.—Jahrb. für Mineral. 1848, p. 392.

‡ Poggend. Annal. xlvii, 506.

§ German edition, ii, 1255.

In Bocksch's collection at Waldenburg, I found two specimens of quartz from a lode, in which there were cavities running in one direction as if water had flowed through them. Here the removal of quartz, that was in the insoluble state, was unquestionable. The solubility of chalcedony in water was ascertained by direct experiment;* consequently, there is a possibility of pseudomorphs of this substance being produced by displacement. But as there are only three minerals that occur with the form of quartz, and as it is uncertain, in the case of two of these, whether displacement has taken place, it would appear that the production of such displacement pseudomorphs is very uncommon.

Brown iron ore and iron pyrites, with the form of quartz.—These pseudomorphs have been found at three places.† As hydrated peroxide of iron is never present in water, it can only have been deposited by water containing protocarbonate of iron; and it is possible that such water may, after the deposition of its iron, dissolve and remove the quartz. But as hollow pseudomorphs consisting of brown iron ore, from which the quartz has been entirely removed, are very unfrequent, the formation of true displacement pseudomorphs of brown iron-ore, with the form of quartz, is limited to special instances; and, generally, these pseudomorphs are merely incrustations of quartz crystals.

As iron pyrites may be produced from carbonate of iron, sulphates, and organic substance,‡ there is a possibility of its being deposited upon quartz crystals, by water containing these substances in solution. But as pseudomorphous iron pyrites, from which the quartz has been entirely removed, has not hitherto been met with, the formation of true displacement pseudomorphs must be regarded as questionable.

There are, on the contrary, displacement pseudomorphs, consisting of quartz with the form of iron-spar, specular iron, and iron-pyrites. In the two latter cases there would appear to be an infraction of the general rule, that the displaced substance is always more soluble than that introduced in its place;§ but it must be remembered that neither sulphide nor peroxide of iron are removed as such, by water, both being converted into proto-compounds, which are more soluble than silica.

Steatite, with the form of quartz. ¶—This pseudomorph is found,

* English edition, i, 59.

† Blum.—Die Pseudomorphosen, p. 294, and Nachtrag, 2, p. 118.

‡ English edition, i, 163.

§ Ibid, i, 39.

¶ Ibid, i, 19.

according to Blum,* under the same conditions as that after bitter-spar, and associated with it.† The quartz at first appears rather opaque, loses lustre, becomes white and very brittle; so that it may be rubbed to a fine, granular powder. Other parts of the mass are soft, dull, yellowish or greyish-white, and consist of steatite. The micaceous schist, near this pseudomorph, is also converted into steatite; which may easily be accounted for, as its constituents, quartz and mica, are both susceptible of this alteration. This steatite, originating from micaceous schist, still presents the schistose structure; and those parts which have originated from mica are brownish colored; probably owing to the amount of iron in the mica. Blum mentions several other places where displacement pseudomorphs, of steatite after quartz, occur. He also points out the conversion of compact quartz into steatite, and is of opinion that most of the steatite, occurring in dykes, has originated in this way.

Blum includes the pseudomorphs of steatite, after quartz, among the alteration pseudomorphs, formed by interchange of constituents. According to this view, a part of the silica of the quartz would have been eliminated, and magnesia introduced in its place; and when the quartz was associated with bitter-spar, the eliminated silica would have combined with the magnesia of that mineral, and produced a further quantity of steatite. But neither of these changes can be supposed to take place, for silica does not decompose magnesian salts in the wet way. Nauck‡ remarks, that independently of this, the amount of magnesia in bitter spar would not have been sufficient for the conversion of both minerals into steatite without diminution of volume; and he coincides with me in opinion that the steatite has been formed by direct deposition of silicate of magnesia.

According to Nauck, the steatite, with the form of quartz, at Göpfersgrün, consists of almost pure silicate of magnesia, with minute traces of protoxides of iron and manganese. The opacity and want of lustre of the quartz, near to the steatite, renders it probable that the displacement of silica, by silicate of magnesia, has been preceded by disintegration of the quartz.

The nodules of steatite in the gypsum, at Stecklenberg, in the Hartz, described by G. Rose,§ present the appearance of being

* Loc. cit. p. 15; and Nachtrag, p. 68.—See also Marx.—Schweigger's Journ. liv, 312.

† See ante, p. 451.

‡ German edition, i, 791 et seq. and ii, 1263 et seq.

§ Zeitschrift der deutschen geol. Gesellschaft, ii, 136.

pseudomorphs after flint, and are analogous to the steatite pseudomorphs after quartz. According to the analysis by Bromeis, they contain, besides the constituents of steatite, as much as 4 per cent. carbon and bituminous substance, originating, probably, from flint.

Blum* points out the frequent occurrence of flint, as nodular masses, in meerschaum. One specimen of this kind presents exactly the appearance of flint; at the interior there is still a nucleus of unaltered flint, which passes into meerschaum in the same manner that quartz passes into steatite. The brown flint, with fatty lustre, becomes dull, paler-colored, and soft, as it passes into the yellowish-white meerschaum. Blum has no doubt of the conversion of the flint into meerschaum, although, from the amorphous character of the flint, this is not indicated by the form.

As meerschaum, like steatite, consists of hydrated silicate of magnesia, there is no question as to the possibility that flint may be displaced by hydrated silicate of magnesia, particularly since my experiments show that the silica of flint passes into the soluble state during disintegration and weathering.

Occurrence of quartz and its production.—The conditions in which quartz is found, are :—

- 1, as a distinct rock, particularly in micaceous schist.
- 2, as a constituent of rocks.
- 3, in dykes.
- 4, in drusy cavities.
- 5, as separate masses in sedimentary rocks.

As a constituent of rocks, it occurs both in the crystalline and amorphous state, but not always recognizable by mineralogical characters. When in the analysis of a rock, the amount of silica is found to be greater than in the most siliceous minerals, such as felspar, it must be inferred, that there is free silica present.

Quartz rock frequently occurs, as layers, in micaceous schist; and, in its purest form, appears as crystalline quartz. A colossal mass, covered with small laminæ of mica, projects, like a wall, from the micaceous schist of the Ural and Taganai; at the latter place it reaches a height of nearly 450 feet. The micaceous schist evidently extended to the same height formerly, and has been removed sooner, owing to its being more liable to disintegration, by atmospheric agents, than quartz is.

The Erzgebirge presents numerous instances of quartz layers

* Die Pseudomorphosen, p. 126.

containing mica. Near Freiberg, one may be traced for a distance of three English miles.* The quartzose schist, near Breitenau, passes into coarse, laminar, micaceous schist, and into gneiss. The ferruginous, quartzose rock, which occurs in the Erzgebirge,† and, together with serpentine,‡ extending to very great heights, is a peculiar formation. It is hornstone, very much fissured and fractured, of a yellow and yellowish-brown colour, and traversed by fine veins of crystallized quartz.

The rocks belonging to the quartzite family, in which Naumann§ includes, besides the several varieties of quartzite, the itacolumite, greisen, schorlaceous quartzite, and crystalline quartzose sandstone, consist almost wholly of crystalline quartz. In itacolumite, the granules of quartz are not coherent, but merely attached by the mica, so that the rock is flexible.

Crystalline quartz occurs, in many sandstones, as layers, consisting wholly of granules of crystalline quartz, or even perfectly formed crystals. The loose layers of sand, in the brown coal deposits, sometimes consist of crystalline granules of quartz. The occurrence of silica, as sandstone, is very extended.

Quartz dykes occur in many crystalline and sedimentary rocks, particularly in clay-slate. The quartz in these dykes is amorphous, and it is only in their drusy cavities that it is crystallized.

Opal occurs in irregular dykes and veins, or as nests, in trachytic rocks, and in serpentine; in sedimentary rocks it has hitherto been found only in the Taunus slate near Wiesbaden.||

Chalcedony occurs as bead-like masses, in porphyry, upon dykes of baryta spar and metalliferous lodes.

Agate occurs upon dykes in gneiss.

Jasper occurs upon dykes in various rocks.

Drusy cavities and hollows in rocks abound in siliceous minerals. The drusy cavities of amygdaloid rocks also contain amethyst, agate, opal, chalcedony, cacholong, carnelian, and heliotrope.

Hyalite occurs upon fissures, and in drusy cavities of dolerite, basalt, trachyte, porphyry, and lava; as an incrustation upon decomposed serpentine; and in stalactitic masses, in clay-slate, and metalliferous lodes.

As all siliceous substances occurring in lodes, dykes, and drusy

* Naumann.—Erläuterungen zu der geognost. Charte des Königreiches Sachsen Heft. 2, p. 80.

† Ibid, p. 204.

‡ Ibid, p. 35.

§ Lehrbuch der Geognosie i, 545 et seq.

|| F. Sandberger.—Jahrb. des Vereins für Naturkunde Heft. 6, p. 6.

cavities, originate from the adjoining rocks,* they must bear a definite relation to the constituents of those rocks, whence they are derived by decomposition. The common and amorphous quartz and rock crystal occur in the dykes and drusy cavities of all rocks, both crystalline and sedimentary. However, it cannot be denied that these anhydrous, siliceous substances occur chiefly in granite, gneiss, micaceous schist, and clay-slate. The other siliceous substances, and particularly opal, are not known to occur in these rocks, with the exception of the micaceous schist, at Bleistadt, in Bohemia, and in fissures of the Taunus slate.

Opal occurs chiefly in trachytic rocks. If the silica of the siliceous substances, in dykes and drusy cavities, has originated chiefly from felspar, by decomposition, it may be conjectured, that in the decomposition of glassy felspar, the chief constituent of trachyte, the silica would be separated in a state peculiarly favorable for the production of opal, while that separated in the decomposition of orthoclase, in granite or gneiss; or of the remains of orthoclase in grauwacke and clay-slate, would be deposited as amorphous quartz, or as rock crystal.

Among the sedimentary rocks which contain silicates, not as essential constituents, and which still contain quartz sometimes; are limestone, marl, and gypsum.

Quartz occurs, not unfrequently, in some kinds of granular limestone. Nodules, nests, druses, and veins of quartz, hornstone, or flint, are very frequent in common limestone. Hornstone and flint occur, in the same manner, in fresh-water limestone. A compact, marly limestone, near Pforzheim, contains very distinct crystals of quartz with sharp edges, generally enclosing some sulphur. A marl, near Posneck, in Thuringia, contains vast numbers of very small and sharp quartz crystals. Numbers of detached, transparent quartz crystals occur in the fields at Hovinia Krieska, in Galicia. Quartz crystals also occur in the gypsum of St. Jago di Compostella, in Spain, and at Gräfintonna, in Thuringia. †

Siliceous limestone is highly impregnated with silica, and contains nests and veins of hornstone or chalcedony, which sometimes pass gradually into the surrounding mass. In other kinds of siliceous limestone, silica is not perceptible; but is indicated only by a greater degree of hardness, and by the difficulty with which

* Breithaupt—Paragenesis, p. 266.—points out that quartz rarely occurs in lodes and dykes traversing rocks that do not contain quartz or silicates.

† Ibid, p. 27 and 43.

the rock is decomposed. The planer-limestone, of Klotzcha, near Dresden, is of this kind, and contains, according to Stöckhardt, from 22 to 48 per cent. silica.

Several naturalists, Spallanzani, Ripetti, Northrop, and Eli Whitney, testify to the formation of quartz crystals from aqueous liquids.* Silliman† gives an account of a milky liquid filling a chalcedony cavity in amygdaloid. When evaporated in the air, small quartz crystals, $1\frac{1}{2}$ inch long, were formed. Another specimen contained a white paste, from which similar crystals were formed as it dried, and which were hard enough to scratch glass.

These frequent and unquestionable observations lead to the opinion, that neither the soft siliceous mass, nor the quartzose substances in the drusy cavities, can have been produced from a liquid with which the cavities had only once been filled; for their mass is, in proportion to the size of the cavities, too large, and the solubility of silica in water, too small, for this to have been the case.

The drusy cavities of amygdaloid rocks are, not unfrequently, quite, or almost quite, filled with siliceous substances. Evaporation goes on very slowly in these cavities; but when opened, it would be more rapid, and the soft mass would harden. If crystallizable silica were dissolved in such a liquid, and the evaporation had advanced to saturation, it may be understood, that on opening the cavity, quartz crystals would be formed; as in the case of any salt dissolved in water under similar conditions. The floating particles of silica are, probably, amorphous; and, therefore, furnish either chalcedony or opal, when dried. The phenomena described by Ripetti and Northrop, indicate simultaneous presence of amorphous and crystallizable silica, and are in conformity with the association of amorphous siliceous substances, and quartz crystals, in the same drusy cavities.

There can be no question that the formation of the large, well developed quartz crystals, which are found in drusy cavities, depends upon the very slow evaporation of water, for the crystals formed from any solution are more perfect, and larger in proportion, as the evaporation is slower.

Quartz crystals have also been obtained artificially. Siegling‡ found, in a very dilute alkaline solution of soluble glass, that had

* German edition, ii, 1279 et seq.

† Amer. Journ. viii, 118.

‡ Wolff.—Lehrbuch der Chemie. 1821, ii, 179.

been exposed to the air for eight years, groups of four-sided pyramidal crystals, that were perfectly transparent, and so hard that they gave sparks when struck with steel, and were not affected by acids. Schafhäütl* found microscopic, six-sided prismatic crystals, with six-sided apices, that were deposited on evaporation, by water, in which he had dissolved silica under pressure.

Becquerel† found, that when laminæ of gypsum were immersed in a very dilute solution of silicate of potash, in a loosely covered vessel, the atmospheric carbonic acid gradually decomposed the silicate, and the carbonate of potash converted the sulphate of lime into carbonate. At the same time granules, or laminæ of silica, separated, which scratched glass, and contained 12 per cent. water. Very thin laminæ, of the same hardness, were formed at the bottom of the vessel; when acted upon with a hot solution of carbonate of potash, they left transparent laminæ, which, when examined with two of Nichol's prisms, presented the colours peculiar to doubly refracting crystals, so that they may be regarded as quartz.

The result of this experiment justifies the conclusion, that in Siegling's experiment, also, it was the atmospheric carbonic acid that effected the decomposition of silicate of potash, and the production of quartz crystals. The addition of sulphate of lime is certainly not an essential feature of the experiment; and, probably, only facilitated the elimination of silica by producing sulphate of potash, which does not, like carbonate of potash, dissolve silica. It is an interesting fact, that in Becquerel's experiment the silica was separated in both modifications.‡

Senarmont obtained microscopic rock-crystal by exposing a solution of silica in carbonated water, or in very dilute hydrochloric acid, under a high pressure, to a temperature of 200° or 300° F. Fremy obtained solid hydrated silica by decomposing sulphide of silicium by means of water. Cross obtained crystallized quartz by decomposing hydrofluosilicic acid, or a solution of silica in potash, by means of the galvanic current.§

As silica is deposited from solution of silicate of soda, and

* Jahrbuch für Mineral, etc. 1846, p. 665.

† L'Institut. 1853, No. 996, and Comptes rendus, xxxvi, 211.

‡ I have also observed that the silica separated from a dilute solution of silicate of soda, in the course of a year and a half, and without the action of carbonic acid, was only partially dissolved by hydrochloric acid.—German edition, ii, 1223.

§ Comptes rendus, loc.cit.

since, according to Siegling, quartz crystals were formed in a solution of soluble glass, containing excess of alkali, the drying of alkaline silicate, in drusy cavities, may give rise to the formation of both amorphous and crystalline siliceous substances.

The minute amounts of alkali in siliceous substances,* and of lime and magnesia in opal,† are the remains of bases with which the silica was combined. Therefore, the probability is increased that the silicates, after deposition, are separated into two different compounds; one, very sparingly soluble, consisting of a large amount of silica, and very small amount of base; the other, copiously soluble, consisting of a small amount of silica, and very large amount of base. The former would remain, while the latter was removed by water. The latter compound occurs in the water of springs; and would, probably, be found in the water of all springs rising from rocks, in which siliceous deposits are still being formed. Consequently, the siliceous substances in drusy cavities may originate, partly, from free silica, and partly from silicates dissolved in water.

Quartz crystals that contain nuclei of a different colour, or have a conchoidal structure, have certainly been formed at different periods, between which intervals have elapsed. Thus, according to Breithaupt,‡ in the grey quartz of Monte-pulciano, in Tuscany, four periods of formation may be traced. All “hauben” quartz is of this kind. Sillem§ describes a quartz crystal, in which a smaller one is enclosed; between them chlorite has been deposited, showing that the formation of the one was not immediately followed by that of the other. In a large crystal, from Schemnitz, in Hungary, there is a smaller, very sharp crystal, with pyramidal ends quite detached. Nothing can furnish more decisive evidence of successive formation; and, consequently, of formation in the wet way, than these phenomena.

In Breithaupt's Paragenesis, there is a drawing of a quartz druse, in which some of the quartz crystals are bent. Since, as Breithaupt remarks,|| crystals never have curved axes, and since these bent crystals generally present actual fractures, he infers, that after the formation of these crystals, and before they had become perfectly hard and brittle, they must have experienced violent flexure.

* See ante, p. 459.

† See ante, p. 461.

‡ Handb. d. Mineral. iii, 667.

§ Jahrb. für Mineral. etc., 1848, p. 110.

|| Paragenesis, p. 11.

However, I am of opinion, that in the formation of a crystal it at once acquires hardness, and all its proper physical characters. Such, at least, is the case in all crystallization effected artificially; and there are no grounds for supposing that it ever takes place in a different manner. I have, on a previous occasion, compared the formation of quartz crystals to that of gypsum crystals upon faggots.* It can take place only by juxtaposition of the molecules; and as the formation of large quartz crystals extends over centuries, it is impossible that such crystals should have remained so long in a soft state.† So long as there was not any disturbing influence, the quartz crystals would remain with the position of their axes unaltered; but when a crystal, in the course of its progressive formation, comes in contact with others in a slanting position, its position would be changed in the same way as when a growing tree, comes in contact with external obstacles. It is evident that such curved quartz crystals must be of rare occurrence; for it generally happens, that a crystal formed over the top of another, hinders the growth of that underneath, by preventing the access of the water, by which its mass would be increased.

Taking a general view of the situations in which crystallized quartz occurs, it appears to be a very remarkable circumstance, that in crystalline rocks it rarely occurs as crystals, and never as large crystals; amethyst never occurs in these rocks. If these rocks are really products of igneous action, it would appear, at least, that the conditions for formation of large crystals did not obtain. But if the formation of granite by fusion were possible, it would appear, that in the solidification of such enormous masses, the slow cooling, and other conditions, would be most favourable to the formation of large quartz crystals. The granite in dykes would solidify more rapidly than the much larger masses, constituting granite rocks; and, nevertheless, the drusy cavities of granite dykes contain the largest quartz crystals, while in granite rocks they are generally wanting.‡ This appears as an inconsistency which must be accounted for by those who would

* See ante, p. 97.

† Schafhäütl – Jahrb. für Min. 1845, p. 859—states that in a block of Carrara marble a cavity was found containing a large quartz crystal in such a pasty and tenacious state that it received any form or impression, but afterwards became solid and opaque. The workmen affirm that this is a frequent occurrence. Unless Schafhäütl himself saw this quartz crystal, there is every reason for doubting the truth of the statement.

‡ See ante, p. 99.

attribute to granite an igneous origin, before the possibility of the formation of quartz crystals by fusion can be entertained.

The possibility of such formation of quartz crystals may, however, be so easily disproved in all instances, that it appears incredible that such a notion should prevail in the minds of mineralogists who have such frequent opportunity of recognizing the obvious evidence furnished by quartz crystals, that they were not produced by igneous action.

The remarks that have been made with reference to rock crystal, are applicable to all quartzose substances. Felspar, when completely decomposed, yields 43·5 per cent. silica, and 40 per cent. kaolin; so that the silica eliminated in this decomposition amounts to as much as the clay deposits, which represent the previously existing felspar.

Those who are accustomed to regard the amounts of substances removed from rocks by solution in water, as small and unimportant, require only to consider the origin of large deposits of clay, in valleys, in order to perceive the error of such an opinion. It has already been shown that masses of quartz occur, corresponding in magnitude to the clay deposits; and it appears to be a necessary inference, that not only the quartz veins in granitic rocks, but also the far more considerable layers of quartz, are deposits from water. In no instance are the characteristic features of such an origin more distinctly marked than in the Erzgebirge. In the alluvial deposits, the thick beds of clay are seldom accompanied by any considerable deposit of silica; for the layers of quartz-sand and pebbles, alternating with the beds of clay, originate from quartzose substances pre-existing in the rocks. By far the greater portion of the silica, equivalent to the beds of clay, has been carried into the sea in solution. There it furnishes not only the material for the formation of siliceous substances by organic agency; but, in all probability, also gives rise to the production of quartzose deposits by displacement; for a greater number of minerals may be displaced by silica than by any other substance; and it is a fact, no less general than remarkable, that when the deposition of substances from sea water cannot be effected by evaporation, it is effected by some process of displacement.

The assumption that enormous masses of quartz have been protruded from great depths, without any attempt to account for the disposition of the silica that has been, and still is, eliminated by the decomposition of rocks, shows want of observation. Since the circulation of water on the earth has gone on, the amount of

silica in sea water has not reached that which is found in the water of springs; and the water of some cold springs contains three times as much silica as sea water does. It cannot be inferred from this fact, that the quantity of silica carried into the sea is inconsiderable; for, notwithstanding the general difficulty of estimating the quantity of substances carried into the sea by the water of rivers, the quantity of silica may be easily estimated; for clay, the equivalent product of the decomposition whence it originated, furnishes a measure of its quantity, and shows that it is far greater than the quantity of silica in sea water.

Rock crystal contains a greater number of different substances imbedded in it than any other mineral. Among these are barytaspar, calc-spar, magnesite-spar, bitter-spar, disthene, topaz, mica, adular, albite, stilbite, chabasite, axinite, tourmaline, epidote, talc, hornblende, actinote, amianthus, chlorite, beryl, titanite, rutile, antimony-glance, scheelite, blende, tin-ore, galena, specular iron, black silver-ore, red silver-ore, silver-glance, metallic gold and silver, mineral pitch, naphtha, and water as detached drops.*

Some of these minerals are known to melt with quartz very easily; others are hydrated; the silver sometimes appears as thin threads traversing the quartz, and the naphtha, water, etc., are not only volatile, but also readily decomposable by heat.

Besides the absence of any material alteration of these substances by the quartz which surrounds them, there is a perceptible regularity in the mode in which quartz crystals are blended with those of other minerals, such as fluor-spar and calc-spar,† showing that in the subsequent crystallization of quartz there has not been any alteration of the form of the previously existing mineral.

The reason why rock crystal contains so many different substances imbedded in it appears to consist in the facts, that silica is dissolved in almost all water; and that when once deposited, it is very sparingly soluble. When carbonates of lime and magnesia are deposited together with silica, they do not become less soluble, and may be subsequently removed by water.

There is no reason why the amorphous, or, at most, crystalline quartz occurring in quartzose rocks, such as granite, etc., should not be supposed to originate in the same manner as the crystallized quartz. Quartz that is colored, and loses its colour when ignited, cannot have been formed by fusion; such, for instance, is the brown rock-crystal from the quarries, near

* Blum.—Oryktognosie, Ed. 3, p. 215.

† Breithaupt.—Handbuch der Mineral. iii, 673.

Mursinak,* and the rose-quartz. These varieties of quartz, and smoke topaz, occur most frequently in granite, less frequently in gneiss and micaceous schist.

The assumption that quartz in granite, and other crystalline rocks, has been produced by fusion, is not based upon any analogy; for quartz crystals have never been found in lava. The quartz that has sometimes been found in lava, is always in the state of rounded pebbles, that have been gathered up by the lava during its flow. The carious state of this quartz shows the influence of heat, and presents a marked contrast to the quartz in granite. Nor is quartz ever separated from furnace slags; it is only when it has been used in too large proportion that it is found imbedded in the slag. Even glass, which contains as much as 81 per cent. silica, separates, when crystallized by continuous heat, into two silicates of definite composition, without any separation of silica.† But in the course of long periods, crystals are formed in the wet way.‡ Whether this is attended with elimination of silica cannot be determined from Brewster's description.

Moreover, the order of succession presented by the minerals constituting granite, and other rocks containing quartz, is directly opposed to the opinion that it has been formed by fusion, and Fournet's attempt to attribute the formation of quartz in this way to a state of superfusion is quite inadequate.

Quartz occurs in crystalline rocks in precisely the same manner as in other situations, where its formation in the wet way is unquestionable. The rock crystal containing other minerals imbedded, is more recent than those minerals. The quartz in drusy cavities, lodes, and dykes, is more recent than the adjoining rocks. Broken crystals and pebbles are frequently cemented together with quartz. In a pebble of red quartzose porphyry, I found a large crystal of quartz broken, and the crack filled with more recent quartz; perhaps this crack was filled after the porphyry had been separated from the rock. Where cavities have been formed in rocks, they are almost always found to contain quartz. Such cavities are continually formed by the decomposition and removal of substances.§ There is, therefore, the greatest

* G. Rose.—Reise nach dem Ural, etc., i, 442,

† Schafhäutl.—Jahrb. für Mineral. etc., 1845, p. 861, and Breithaupt.—Paragenesis, pp. 68 and 69.

‡ See ante, p. 97.

§ The quartz crystals between the laminæ of shells show that when silica crystallizes from water, it makes room for itself.

analogy between these cases and granite, syenite, etc., in which quartz has filled the spaces left by the other minerals. Quartz, appears therefore, in all cases to be a product of the decomposition of silicates in the wet way.

Quartz, with the forms of other minerals.—There are no less than twenty-seven displacement pseudomorphs of quartz after other minerals, and here again quartz appears as the more recent product. The circumstance that silica, which is so generally present in the water of springs, rivers, and the sea, should have displaced other minerals most frequently, is certainly not accidental, and is calculated to produce more correct opinions as to the nature of the pseudomorphic process.*

There is a remarkable antithesis between calc-spar and quartz in their pseudomorphic relations. Quartz exceeds all other substances in the number of minerals whose form it presents, while there is no mineral after which so many others are pseudomorphous, as calc-spar. Both silica and carbonate of lime are very generally present in the water of springs and rivers. It probably often happens that the silica of water percolating rocks is substituted for the substance of other minerals at the same time that carbonate of lime is dissolved by the water.

Quartz, semi-opal, chalcedony, hornstone, cornelian, prasem, and ferruginous quartz, with the forms of calc-spar.—All these displacement pseudomorphs have uneven, drusy, or reniform surfaces. They are generally hollow and drusy, but sometimes solid or only slightly porous. Sometimes they contain remains of calc-spar with corroded surfaces, and, sometimes a nucleus of siliceous substance. The hornstone pseudomorphs present a striped appearance like some very finely banded agate. The ferruginous quartz pseudomorphs generally present several concentric crusts, each with the form of the calc-spar crystal.

In one specimen of quartz pseudomorph, the silica had not only formed a coating over the surface, but had also penetrated between fissures in the crystal, parallel to the cleavage, and the laminæ of quartz had formed cells with the rhombohedral form of the calc-spar. If evidence were still wanting that these, like all other pseudomorphs, have been produced in the wet way, it would be furnished by these quartz laminæ in the crystals; for it cannot be supposed that the quartz penetrated between the cleavage surfaces otherwise than in solution. Friesleben actually found water and air bubbles in the thin drusy crusts of which the

* Zeitschrift der deutschen geol. Gesellschaft, ii, 10.

obtuse rhombohedrons of the quartz pseudomorphs sometimes consist.

As a consequence of the penetration of water between the surfaces of cleavage, the space would be widened by the solution of a proportionate quantity of carbonate of lime. The hollow character of most quartz pseudomorphs after calc-spar, indicates distinctly that the quantity of the more soluble carbonate of lime dissolved was greater than that of the less soluble silica deposited. In the case of those quartz pseudomorphs which are solid, it must be supposed that the deposition of silica continued after the removal of the carbonate of lime. When the water contained silica in both the amorphous and crystallizable state, compound pseudomorphs would be formed, like those of Kupferberg.*

It is very deserving of notice, that carbonate of lime may be displaced by almost all siliceous substances, and, consequently, it is possible that entire layers of limestone may be displaced by silica. This may serve to account for some remarkable instances of the occurrence of quartz layers, the production of which cannot be ascribed to organic agency in the sea. It is probable that siliceous limestone has originated in this manner. But when the carbonate of lime was amorphous, as is the case with most sedimentary limestone, such a displacement cannot be recognized mineralogically. Breithaupt states that in the more recent cobalt-nickel formation, calc-spar is frequently displaced by quartz.

Quartz and chalcedony, with the form of bitter-spar.—These pseudomorphs occur together with those of bitter-spar, after calc-spar,† the apices consisting of bitter-spar, and the remainder of quartz. In one specimen, Blum‡ observed remains of calc-spar under the thin crust of bitter-spar. It would appear, therefore, that in the first instance, hollow pseudomorphs of bitter-spar were formed by water containing carbonate of magnesia, and that, subsequently, silica was deposited in the interior.

The displacement of carbonate of magnesia by silica is instanced by the quartz and chalcedony pseudomorphs after bitter-spar.§ The inner surfaces of these pseudomorphs are but slightly rough, and there are no signs of deposition of quartz towards the interior.

This circumstance shows distinctly that the bitter-spar

* Haidinger.—Poggend. Annal. lxx, 617.

† See ante, p. 49.

‡ Nachtrag, p. 134.

§ Blum.—Die Pseudomorphosen, pp. 237 and 247, and Nachtrag, p. 136.

acted as a precipitant of the silica; and that, after the whole of it was removed, no more silica was deposited. At the interior of these pseudomorphs there are generally nuclei of bitter spar; but, as they are unconnected with the quartz crusts, it would appear they were, formerly, larger, and occupied the entire space.

Quartz and hornstone with the form of iron-spar.—Blum describes several pseudomorphs of this kind, consisting of thin crusts made up of quartz crystals. Here and there, thin layers of quartz extend into the cavity in directions corresponding with the cleavage planes of the iron-spar crystals. The hornstone pseudomorphs are hollow and are implanted upon quartz. The laminae representing the cleavage planes always consist of crystalline quartz.*

Quartz also displaces zinc-spar, siliceous zinc-ore, and carbonate of lead; so that with the exception of carbonates of baryta, strontia, and copper, all earthy and metallic carbonates that occur as minerals may be displaced by silica. Even these three carbonates are susceptible of displacement, and it is probable that quartz pseudomorphs after them will yet be found.

Quartz with the form of gypsum-spar.—These pseudomorphs are either solid or hollow; in the latter case the inner surfaces are rough, or covered with white, reniform chalcedony. The outer surface is rough, uneven, and dull.†

Owing to the much greater solubility of sulphate of lime than of silica it is very difficult to account for the production of these pseudomorphs. Assuming that the water which removed the gypsum, contained $\frac{1}{10000}$ silica, the largest amount that has hitherto been found in the water of cold springs, every particle of water that deposited its silica would dissolve $\frac{1}{400}$ its weight sulphate of lime, or, in other words, the sulphate of lime removed would amount to 22 times as much as the silica deposited. However, it is possible that silica was subsequently deposited within the crust, for the filling of hollow spaces with silica is a very frequent phenomenon.‡

Quartz and chalcedony with the form of baryta-spar.§—Quartz pseudomorphs after baryta-spar occur frequently, and upon a very gigantic scale. Externally they are rough, uneven, and drusy, with the apices of very small crystals projecting. Internally they

* German edition, ii, 1304.

† Ibid, ii, 1306.

‡ See ante, p. 478.

§ English edition, i, 434.

are either filled with quartz, or partly hollow, in which case the quartz appears as large crystals. Most of these pseudomorphs when broken across, present fine layers of peroxide of iron, which so frequently occur upon the faces of the baryta-spar crystals, and indicate the size of the crystals. These layers occur likewise in compact quartz, and indicate that silica not only displaced the substance of the crystals, but also filled up the spaces between the crystals.

In the nodular masses of amethyst in the amygdaloid at Oberstein, Blum * found displacement pseudomorphs of quartz after baryta-spar, which is remarkable, because hitherto baryta-spar has not been found in this rock.

Breithaupt † states that the baryta-spar is an essential constituent of the more recent cobalt-nickel formation, but that it is frequently displaced by quartz. In the Schneeberg lodes the pseudomorphous quartz has been worked for distances of 1000 or 2000 feet. When baryta-spar occurs it is younger than the quartz.

At the Granen-stein in the Frauensteiner Wald there is a thick dyke consisting of quartz which, according to Sandberger, ‡ was originally, for the most part, if not entirely, baryta-spar. §

The sulphate of baryta is much less soluble than silica; the latter is present in the water of every spring, but the former has never been found in water. Displacement of sulphate of baryta by silica appears, therefore, to be inconsistent with the general rule observed in the case of pseudomorphs. || However, it can scarcely be supposed that sulphate of baryta was removed by water without alteration. ¶

Mohs states that at many places iron pyrites occurs in the quartz crusts of the pseudomorphs after baryta-spar. Blum states also, that many of the quartz pseudomorphs, from the lodes at Rhonitz in Hungary, are covered with very small iron pyrites crystals that have been converted into brown iron-ore, and upon the quartz pseudomorphs, in the Schapbach Valley, in Baden, crystals of copper pyrites occur here and there. It is not at all improbable that these metallic sulphides have been produced at the cost of baryta-spar that has been decomposed by organic

* Nachtrag, p. 128.

† Paragenesis, pp. 218 and 222.

‡ Jahrb. d. Vereins für Naturkunde im Herz. Nassau Heft. 6, p. 10.

§ German edition, ii, 1307.

|| English edition, i, 39.

¶ Ibid, i, 450.

substance in the water. Hepatite shows that baryta-spar, like all earthy and alkaline sulphates, is decomposed by organic substance in the wet way. The sulphide of barium produced in this way is very soluble in water, and it is, therefore, not improbable that sulphate of baryta is removed in this way, while silica is deposited in its place. The sulphide of barium thus produced might afterwards be concerned in the production of metallic sulphides.

Amar* states that near Valecas in Spain, chalcedony occurs as pseudomorphs after baryta-spar in the drusy cavities of meer-schaum.

Quartz with the form of baryto-calcite.—These displacement pseudomorphs occur, according to Zippe,† upon the metalliferous lodes at Mies in Bohemia, although not a trace of baryto-calcite occurs there. These pseudomorphs are hollow, cellular, and rough outside.

Quartz, chalcedony and hornstone with the form of fluor-spar.—Quartz occurs at several places, with the forms of fluor-spar, most frequently as octahedrons and cubes, more rarely with other forms. The enormous extent to which fluor-spar is displaced by quartz has already been pointed out.‡ These pseudomorphs are sometimes solid, sometimes hollow, with small quartz crystals upon the inner surface; sometimes also they contain remains of fluor-spar inside. Upon the baryta-spar lodes, near Schriesheim, Blum found very thin shells of quartz that had covered fluor-spar which had been entirely removed.

R. W. Fox§ describes pseudomorphs from a copper vein in “killas,” at the depth of about 160 fathoms. They appear to him to indicate that a succession of changes must have taken place in the condition of the mineral vein from which they were taken. Many of these pseudomorphs contained water that was nearly tasteless, or saline in a very slight degree, and had no reaction upon litmus paper. Other portions contained chloride of sodium, sulphate of iron, lime and hydrochloric acid. This water had a very acrid taste, and one portion contained excess of acid. Some of these pseudomorphs were either wholly or partially filled with crystalline quartz, others were empty, or enclosed fragments of fluor-spar. One cavity contained about a hundred such fragments

* Die Pseudomorphosen, p. 244.

† Ibid, p. 236.

‡ English edition, i, 35.

§ Edinb. new Phil. Journ. xl, 115.

independent of the very small ones. All of them were corroded, and showed in their rounded edges and carious surfaces, the results of the action of a solvent that penetrated readily between the cleavage surfaces.* Besides the fragments, perfect octahedrons of fluor-spar were found in the same specimen, but they were more surrounded and protected by quartz. The quartz containing the imbedded crystals consisted of parallel, translucent and milk-white layers of unequal thickness. It is very worthy of notice that octahedrons of fluor-spar were subsequently formed upon the quartz and were then covered with silica either amorphous, or as small crystals; octahedrons of fluor-spar again occur upon these. In some instances these changes appear to have been repeated again and then a thick crust of quartz with small quartz crystals to have been formed upon the surfaces. Some specimens consisted of one or more layers of quartz between two or more layers of fluorspar.

Fox admits that these phenomena can be accounted for only by the presence of water, and the displacement of substances at different periods. But he ascribes its circulation to causes which have effected the opening and closure of the fissures; to the ascent of hot water and the descent of cold water; to the hydrostatic pressure of sea water, etc. It is unnecessary to refute these assumptions, for all pseudomorphic changes may be referred to the action of water penetrating from the surface into fissures and determining the interchange of substances. Water that effected the substitution of quartz for fluor-spar at the upper portions of a lode would again deposit the dissolved fluoride of calcium at lower parts, and such a change might be very frequently repeated. It was not the substances found in the water by Fox, that effected the pseudomorphic changes, but it was the silica and fluoride of calcium which in so small a quantity of water could not be recognized. But the substances that were found, account for the presence of peroxide of iron, copper pyrites, and iron pyrites upon the sides of the cavities in fluor-spar. One quartz pseudomorph is described as full of fragments of fluor-spar, mixed with fragments of iron-spar and earthy carbonate of iron. In one instance the pseudomorphous quartz presented the form of iron-spar.

Chalcedony is also pseudomorphous, presenting the cubic form

* When alum crystals are immersed for some time in water, the solution commences at the cleavage planes, and fragments, similar to those of the fluor-spar in the above instance, are detached; this is a direct proof of the penetration of water in the direction of the cleavage planes.

of fluor-spar, the pseudomorphs being sometimes solid and sometimes hollow.*

As the specific gravity of chalcedony is 2.55, and that of fluor-spar 3.14, the silica requisite for entirely filling the space occupied by the displaced fluoride of calcium need not amount to more than 0.8 of the latter. According to Wilson, fluoride of calcium dissolves in 26923 parts water, and a very small amount of silica in the water by which the fluoride was removed would be sufficient for the formation of solid pseudomorphs. The water of the springs above-mentioned† contains nearly the requisite amount of silica.

Small hollow, regular cubes, and hollow rhomboidal dodecahedrons of hornstone, with slightly drusy surfaces, described by Freiesleben‡ as occurring in the Schneeberg district, are evidently incrustation pseudomorphs after fluor-spar.

Among the quartz pseudomorphs, those presenting the forms of calc-spar, baryta-spar, and fluor-spar occur most abundantly. As Breithaupt§ justly remarks, it must not be inferred from the small number of rare quartz pseudomorphs found in museums, that the changes in which these minerals are concerned are inconsiderable; in many lodes these spathic minerals have entirely disappeared, and their previous existence is recognizable only by means of pseudomorphs.||

Hornstone with the form of mica.—Reuss¶ states that upon the metalliferous lodes at Zinnwald in Bohemia, pseudomorphs of this kind occur. He describes them as hollow, drusy, and seated upon quartz.

The quartz pseudomorphs confirm what was previously stated with regard to the formation of quartz. The elimination of quartz from silicates extends throughout all periods of mineral formation. The formation of felspar is succeeded by its gradual decomposition, one feature of which is the elimination of silica. After the deposition of the grauwacke, the gradual decomposition of its felspathic constituents commenced. This decomposition progressed as the grauwacke gradually rose above the sea level, and is still going on at the present day, as is shown by the silica in the water of springs rising out of the grauwacke. The silica

* Blum.—Loc. cit. p. 244.

† See ante, p. 463.

‡ Blum.—Loc. cit. p. 249.

§ Paragenesis, pp. 128 and 202.

|| German edition, ii, 1309.

¶ Die Pseudomorphosen, p. 253.

eliminated would be in part, removed by water; in part, deposited in fissures. Similar changes would take place in any rock containing felspar or felspathic remains.

Quartz also displaces galena, scheelite, specular iron ore, iron pyrites and pyromorphite.

Displacement of organic substances by silica.—The silicification of trees in the coal strata has already been treated of.* Briesch† states that a pile of Trajans bridge across the Danube near Vienna was found to be converted, to the thickness of half an inch from the surface, into agate, and that the interior mass was slightly silicified. Trunks of trees a few feet under the present bed of the Elster near Gera, were converted to a thickness of two inches into hornstone, while the interior mass still consisted of serviceable wood.‡

Upon the island Unga on the north coast of America, blocks of wood and whole trunks of trees, some of which distinctly present the marks of hatchets, are found, according to Grewing§ silicified. It would appear, therefore, that even within historic periods silicification may be effected by water containing much less silica than the springs previously referred to.¶

The whole of the desert between Cairo and Suez is covered for a distance of about 86 miles with silicified trunks of trees, sometimes 40 or 50 feet long, and 1 or 2 feet thick. Breist¶ states that they lie in all directions, and brings forward grounds for the opinion that they were silicified on the spot.**

The very minute amount of carbon in the silicified wood from Lough Neagh;†† and in wood-opal I‡‡; and the entire absence of carbon in the fibrous wood-opal II, shows that the displacement of ligneous substance may be entire.

L. v. Buch§§ was led to infer from his observations, that in the silicification of shells, carbonate of lime is never acted upon directly, but that only the organic substance is displaced by silica.

Petzholdt|| attempted by careful investigation to prove that,

* English edition, i, 312.

† Lehrbuch der Geologie, ii, 491.

‡ Breithaupt.—Handb. der Mineral. iii, 681.

§ Heidelberger Jahrbücher d. Litt. 1851, No. 16, p. 235.

|| See ante, p. 463.

¶ L'Institut. 1846, No. 634.

** German edition, ii, 1242.

†† English edition, i, 312.

‡‡ See ante, p. 460.

§§ Ueber die Silicification organischer Substanzen, etc., Berlin, 1831.

||| Silicification organischer Körper, Halle, 1853.

1. The silicification commences at the surface.
2. That in every case the calcareous substance is acted upon.
3. That the formation of siliceous warts and rings, described by v. Buch, is not necessarily combined with silicification; and,
4. That there is no evidence to show that the presence of organic substance is a requisite condition of silicification.

Petzholdt found that when silicified *belemnites* were broken in two, the silicification appeared to have commenced at the surface, extending along the fine tubes in the longitudinal axis, and even along the delicate interstices of the calcareous substance, thus establishing a siliceous connection between the interior and exterior. A silicified oyster shell presented similar characters, and a piece from the centre consisted of,

Silica	....	....	....	....	....	....	51·78
Carbonate of lime, with trace of peroxide of iron	....						47·81
							<hr/> 99·59

As the space required by the silica deposited, is much greater than the fine capillary interstices of the calcareous substance, carbonate of lime must have been removed. Several small shells consisted of,

Silica	....	....	....	97·49
Alumina	....	....	....	} 2·05
Peroxide of iron			....
Carbonate of lime	....			trace
				<hr/> 99·54

In this instance, therefore, the silicification was complete, but no warts or rings were recognizable. However, the greater number of these shells do present warts or rings. Lastly, the amount of organic substance in shells—in oyster shells it is only 0·5 per cent.—is so disproportionate to that of the silica deposited when the silicification is complete, that it cannot be supposed to have any sensible influence.

The penetration of silica into the delicate interstices of the calcareous substance, and the whole of the characters presented by silicified shells correspond so closely with those of the pseudo-morphous siliceous substances produced by the displacement of calc-spar, and the penetration of silica into shells, is so analogous to its penetration between the cleavage surfaces of minerals* that there cannot be any doubt as to these changes having been effected in the same way. There is, however, this difference

* See ante, p. 484.

between the displacement of the carbonate of lime constituting shells, and that of carbonate of lime constituting calc-spar; that the quartz pseudomorphs after calc-spar are generally hollow, while the silicified shells are generally solid. This difference might be ascribed to the tendency of silica to combine with organic substances, if the amount of organic substances in shells were not so small. The recognition of the true cause of this difference remains for future investigation.

In the chalk marl near Hamm in Westphalia, white, chalky masses occur, which generally effervesce copiously with acids, but rarely dissolve entirely. The flints occurring in the same locality, are also covered with the same substance. In several fragments of this substance occurring with and without flint nuclei, W. von der Mark* found the proportions of substances soluble, A, and insoluble, B, in hydrochloric acid to be:

A 7.4; 9.5; 10.2; 26.3; 48.0; 55.0; 58.8; 66.4; 67.5; 98.5.
B 92.6; 90.5; 89.8; 73.7; 52.0; 45.0; 41.2; 33.6; 32.5; 1.5.

In almost all instances hydrochloric acid dissolved only carbonate of lime.

The following analyses by von der Mark are also connected with this subject:—

	I.	II.	III.	IV.	V.	VI.	VII.
Silica	97.01	88.63	86.9	97.11	96.65	95.13	90.03
Peroxide of iron	0.76†	0.74	0.7†	0.83	0.78†	trace	trace
Carbonate of lime ... ..	...	8.26‡	9.1	0.85	0.64	...	2.43
" magnesia ... ..	...	0.18	...	0.06	0.20	...	2.80
Lime	0.66	0.90	...	...	...	0.78	...
Magnesia ... ..	...	...	...	...	...	0.15	...
Alkalies	1.50§	0.12§	...	0.16	0.43	0.08	0.17
Water	1.16||	1.08	3.3	1.12||	1.40||	4.00||	4.00||
	100.09	99.91	100.0		100.10	100.14	99.43

I and II. Flint from the same locality.

I. Interior black, hard nucleus.

II. Soft white crust.

III. Float-stone; analyzed by Graf Schaffgotsch.¶

IV and V. Flint from arable land.

* Verhandlungen des Naturhistorischen Vereins der preuss. Rheinlande und Westphalen, Jahrgang 10, 1853, p. 385 et seq.

† With alumina.

‡ With 0.09 per cent. phosphate of lime.

§ Potash.

|| With organic substance.

¶ Poggend. Annal. lxxviii, 150.

IV. Nucleus.

V. Whitish-yellow, hard crust.

VI and VII. Flint from the Paris basin.

VI. Nucleus.

VII. Crust—float-stone—

The crust represented by II, cannot have originated from the flint represented by I, by displacement of lime by potash, as in the case of the flint knife-blade, analyzed by Berzelius; * for it contains more lime and less potash than the flint. Still less can it be assumed that the above-mentioned chalky substance—float-stone, containing 67·5 per cent. carbonate of lime, is decomposed flint.

The same organisms which contribute essentially to the formation of chalk, are found also in flint. The corals, with innumerable small pores, would be easily converted into siliceous fossils, in the porous chalk; although the effervescence of these substances with acid, shows that some particles of the calcareous shell remains, and renders it probable that the lime in flint is combined with carbonic acid. The more solid shells of bivalves are less liable to penetration of water, and, consequently, less liable to silicification. These shells are still found in flint, while the calcareous substances of *mollusca*, etc., is displaced by silica. In many instances, calcareous shells are not silicified, but the carbonate of lime is removed by water, leaving a cast of the interior, consisting of flint.

The inference drawn by von der Mark, from his observations, is, that the flint in the Westphalian chalk-marl has been produced by displacement of carbonate of lime, both of chalk and of the organisms, by silica; and that the chalky masses—float-stone—originate from chalk in the same manner.

I am disposed to agree, entirely, with this opinion, which is completely consistent with facts already mentioned† as to the occurrence of calc-spar in flint.

The flint represented by IV is analogous to that examined by Berzelius. Two specimens of crust formed upon flint, by weathering, were analyzed by von der Mark, who found that the amount of alkali varied from 0·07 to 0·43 per cent.; and that, in unaltered flint, it was from 0·16 to 0·5 per cent. Hence, he infers, that in the disintegration of flint, consequent upon weathering, some silica, and the colored organic substance is elimi-

* English edition, i, 8.

† See ante, p. 466.

nated; while water is introduced, and, perhaps, alkali also.* The float-stone represented by VII, does not appear to be weathered flint.

Connected with the above observations, are those made by Petzholdt,† in relation to similar instances of displacement of carbonates by silica, in dolomite.

	VIII.	IX.	X.	XI.	XII.	XIII.
Silica	98.83	81.13	2.31	4.73	4.09	97.55
Alumina	1.17‡	....	3.38	5.45	4.92	2.08||
Peroxide of iron } ....	....	11.01§	} 94.31	89.82	{ 49.01	....
Carbonate of lime ....	....	7.84				
" magnesia ....	....	....			{ 41.34	0.54
	100.00	99.98	100.00	100.00	99.36	100.17

VIII and IX. Hornstone nodules, from the dolomitic layers of the Silurian strata, at Addafer, Lievland.

VIII. Nucleus.

IX. Crust.

X. Dolomite, close to the hornstone nodules.

XI. Dolomite, from a distance of four inches from the hornstone.

The analyses, X and XI, show, that there is a sufficient amount of silica, in dolomite, for the formation of hornstone. The smaller amount of silica in the substance represented by X, shows, that in the immediate proximity of the hornstone, silica has been extracted from the rock.

The presence of carbonate in the substance represented by II, admits of the inference, that in this instance the displacement by silica was not completed; for if the hornstone nodules were deposited in hollow spaces, they would be homogeneous throughout.

The circumstance that the water permeating dolomite should remove the less soluble silica present in such small amount, and not the more soluble and more abundant carbonates, may appear

* This alteration is analogous to that of the opal mentioned at p. 461, in so far as the silica decreases and the water increases in amount. Perhaps also in the case of opal the decolorization is effected by removal of organic substance.

† Loc. cit. p. 20.

‡ With carbonate of lime.

§ With traces of alumina and peroxide of iron.

|| With carbonate of lime and traces of peroxide of iron.

remarkable, and as difficult to account for, as in the case of similar substances in the chalk. But as the free carbonic acid in the water would soon be consumed in the formation of bicarbonate of lime, no further solution of carbonate of lime would take place, although silica might be dissolved to such an extent, that the water would be capable of effecting displacement of carbonate of lime by silica. However, the water must retain some carbonic acid, or it would not be capable of removing the carbonate of lime. It is, therefore, evident that there must be a combination of several circumstances to bring about the production of these hornstone nodules.

XII. Dolomite, from the same locality.

XIII. A white, porous, friable, siliceous substance, which frequently occurs in this dolomite.

This substance does not present any sharp or regular distinction from the surrounding dolomite; and, consequently, Petzholdt regards it as a product of its silicification.

Comparison of the analyses VIII and XIII with I and IV, shows a close correspondence between the hornstone, in dolomite, and the flint, in the chalk. The substance represented by II, is imperfect flint; that represented by IX, is imperfect hornstone; but, in the former instance, the displacement is further advanced than in the latter. As the substances represented by VIII and XIII are nearly identical in composition, and differ only in the state of aggregation, both may be supposed to have the same origin. Whether the substance represented by XIII would become hard in the course of time, and be converted into a substance like VIII; or, whether different circumstances would produce differences in the state of aggregation, cannot be determined; but the former case seems to be the more probable.

Ehrenberg* found that the infusorial beds, near Rolt and Geistingen, do not contain any empty shells; but that all the small, siliceous shells, are filled with siliceous substance.

Consequently, there are two different processes concerned in the production of these beds; first, the production of siliceous, infusorial shells, by organic action; and, second, the deposition of silica in the hollow spaces of these shells, and in drusy cavities and fissures. These processes of alteration are very remarkable, because they illustrate the conversion of infusorial layers into solid, siliceous rock.

In the volcanic tuft of the Brohl valley, at the lake of

* Sitzungsberichte der Berliner Akad. der Wissens. Mai, 1846.

Laach, and at the Hochsimmer; in the beds of black rapilli, between it and the Forstberge, Ehrenberg found infusorial shells. Both mountains are extinct volcanoes, with well-defined craters and extensive lava streams; so that abundant vestiges of organic action appear associated with products of volcanic action at the surface. Ehrenberg is of opinion that the materials acted upon by volcanic influence, were tertiary strata, all belonging to the epoch of *leuciscus papyraceus*; and similar deposits, sometimes unacted upon by volcanic influence, have been formed in the Westerwald, in the Vogelsgebirge, near Cassel and Bilin.

These forms of the tertiary period are chiefly fresh water organisms; the marine organisms are few in number, and occur only here and there in the brown-coal strata.

It would appear that there are three possible ways in which *infusoria* may be produced in the neighbourhood of extinct volcanoes. Either they existed in sedimentary strata before the outbreak of the volcano, or they were produced after the tuff and rapilli had been deposited under water; or thirdly, that the *infusoria* were introduced by water. The former origin is probably that of the fresh water, siliceous *infusoria* and *phytolitaria* thrown out of Hecla in 1846. The second origin has probably obtained in the neighbourhood of the lake of Laach, in the lake itself, and in the meres of the Eifel which are rich in various forms of siliceous organisms.

The third mode of origin can scarcely be questioned for Ehrenberg,* found, in some fragments of the opal from the dolerite of Steinheim, in the serpentine of Kosemitz, and in the porphyry of Kaschau, round substances similar to those in flint, but for the most part homogeneous at the interior. Bowerbank† also states that he has found microscopic organisms in the moss agate of Oberstein, in Egyptian agate, and in the Indian jasper. With the exception of Egyptian agate, all these minerals are stated to present indications of having originated from sponges.

Ehrenberg informs me that in the Egyptian jasper he has found *polythalamia*, but that in 200 thin plates of agate, mostly from Oberstein, he did not find any organic structure. Göppert‡

* Poggend. Annal. xxxviii, 462.

† Geol. Soc. Ann. of Nat. Hist. 1842, viii, 460.

‡ Archiv für Mineral. xxiii, 73 et seq.

MacCulloch.—Transact. of the Geol. Soc. ii, 511—describes substances resembling vegetable forms imbedded in chalcedony.—H. Rose ignited a plate of chalcedony, in which was an apparent representation of a *conserva*, and found that the green lines were not destroyed, but became brown, showing that they were protoxide of iron.

was also unable to recognize anything of this kind, but he describes a remarkably well preserved fern imbedded in chalcedony.

If it is certain that opal in dykes and drusy cavities of trachyte, and in fissures of serpentine, etc. is a product of infiltration, it is quite possible that *infusoria* may be conveyed into such spaces in rocks by means of water. However, Ehrenberg infers from numerous observations that there are no grounds for supposing this to be the case.*

Alteration of siliceous substances.—The alteration of opal and flint consists, partly, in the introduction of water and a small quantity of bases; partly in the substitution of small amounts of bases and separation of silica.

Quartz pebbles, although under the most favorable conditions for alteration, generally appear quite unaltered. They are sometimes carious, and so friable that they may be broken between the fingers, but then, they are generally intersected by veins of hydrated peroxide of iron, so that there is no doubt that proto-silicate of iron was present, which, being decomposed by the oxygen and water of the atmosphere, produced this state of the quartz pebbles.

Quartz occurs in almost all lode-formations, partly, and most abundantly as the oldest mineral, sometimes as the most recent mineral, when the lodes contain silicates such as feldspar, garnet, augite, hornblende, etc., by the decomposition of which, silica is liberated; † it also occurs as displacement pseudomorphs.

In the noble quartz formation, the quartz, which preponderates, is generally attached to the adjoining rock, and not unfrequently interlaced with it. This circumstance is a distinct indication of the origin of the quartz.‡

The great number of minerals after which quartz is pseudomorphous, affords special evidence of the constant elimination of silica. This displacement of large masses of calc-spar, barytaspar, and fluor-spar in lodes, admits of the inference, that a time may come, when, in lodes traversing feldspathic rocks, these substances will be entirely displaced by quartz.

* It would appear to be strange that the *gallionella ferruginea*, which is found at depths of 1,100 feet below the surface, should be conveyed there only through the shafts of mines, and not through the natural fissures of rocks.

The Berlin infusorial strata is in a condition which proves the power of propagation of great masses of individuals.—English edition, i, 199.

† For instance in the augite-garnet, pyrites and blende formation, and also in the titanium formation, where albite and adular are older than the quartz.—Breithaupt.—Paragenesis, pp. 134 and 137 et seq.

‡ Ibid, p. 148.

The siliceous substances produced by organic action, furnish equal evidence of the continual elimination of silica. It has already* been shown that silica is introduced into plants, frequently in large amount, and also that the water penetrating through the thin layer of vegetable earth, abstracts silica from the silicates it contains.

A pound of hay, growing upon a square metre of meadow, abstracts $\frac{1}{50}$ pound of silica annually. If the water introduced into the grass, from the soil, contains as much silica as the water of the previously mentioned springs,† 763 pounds of water must be annually transferred to the grass, from this extent of soil. This would be about two-fifths of the quantity of water annually deposited from the atmosphere. Consequently, there is no need of assuming, that the solution of silica is effected by peculiar processes, taking place in the vegetable soil; the amount found in the water of fresh springs, together with the quantity of water deposited from the atmosphere, is quite adequate for the requirements of plants.

If, however, the silica, instead of being introduced into hay or straw, were deposited as a quartz layer, it would, in 78705 years, acquire a thickness of one foot, and the formation of the most enormous quartz layers may be accounted for in this way.

It follows, therefore, that the deposition of quartz is a process which has gone on interruptedly since the earliest periods, and is still in progress. Hence only, can the occurrence of quartz, with many forms and modifications, be accounted for.

CHAPTER XLIII.

MAGNETIC IRON-ORE.

THE iron-ores will be treated of as a class in the following volume, but magnetic iron-ore is more appropriately treated of here, because among these ores, it is the only one which occurs universally as an independant mineral, in a great number of rocks.

Magnetic characters.—This mineral is one of the few that are magnetic, and it is the only one that is frequently polar. It com-

* See ante, p. 115.

† See ante, p. 463.

municates this character to rocks, even when it is present in them only to a small amount, and sometimes in such degree that these rocks produce a deflection of the magnetic needle at considerable distances.

At the Heidelberg near Celle, in the Fichtelgebirge, v. Humboldt * found a very pure serpentine rock which presented such a high polarity, that, at a distance of twenty-two feet the magnetic needle was deflected. The mountain presents, at the northern declivity, only south polarity; at the southern declivity, only north polarity; but towards east and west there are frequent points of indifference. The smallest fragments of rock present distinct poles, and a distinct magnetic axis. Notwithstanding this great polarity, the rock exercises no influence whatever upon unmagnetic iron, but it is stated that, when powdered, the particles of dust are attracted by an artificial magnet. On a subsequent occasion, v. Humboldt stated that at the Heidelberg, hornblende schist occurs, which presents the same magnetic characters as the serpentine, but that fragments of both rocks are met with which are entirely inert, as had been observed by Charpentier. Humboldt was unable to detect any difference between the active and inactive fragments. In general, those pieces that have the least density are the most active. Some fragments contained magnetic iron-ore distributed through them; but when these are powdered the whole of the powder is attracted by a feeble magnet. From the powder of one fragment that had a very decided polarity, he extracted 1·5 per cent. magnetic iron-ore, and from the powder of a fragment that was quite inactive he extracted almost 0·5 per cent.

These unusual phenomena induced me to undertake some experiments myself.† I found that the magnetic needle was considerably deflected near the Heidelberg, and that a detached piece of serpentine, three inches long, two inches broad, and one and a-half inch thick manifested sensible polarity at a distance of six inches. When the polarity of each of the projecting corners was examined, it was easy to find a sectional plane, that separated all the north poles from the south poles. Other fragments of serpentine presented the same characters; and some from other localities in the Fichtelgebirge were polar only at particular parts, at others they attracted both poles of the magnetic needle.

* Neues Journ. der Physik von Gren. iv, 136.

† Ueber die magnetischen Eigenschaften einiger Gebirgsarten des Fichtelgebirges.—Schweigger's Journ. 1816, xviii, 297.

I extracted from the powder of one piece of serpentine, 10 per cent. magnetic powder. This cannot be regarded as the quantity of magnetic iron contained in it, because it would be impossible to effect a perfect separation by this means.

Zimmerman * found at Schloss Frankenstein, near Darmstadt, an olive-green variety of serpentine, containing much hornblende, and so magnetic that a piece weighing three quarters of a pound, distinctly attracted and repelled the magnet at a distance of six feet. The magnetic polarity of the serpentine at the Auschkul lake is so great at one place, that according to Kupffer,† the the magnetic needle is reversed.

A piece of hornblende rock from the Heidelberg, measuring six inches by four, and one inch and a-half thick, manifested at one side the most decided south polarity, at the opposite side, beyond the line of indifference, both poles of the magnet were equally attracted. But after a piece, an inch long, had been broken off, the north pole appeared very distinctly at the surface of fracture. The detached piece had also a north pole at the surface of fracture, and at the opposite end, which before attracted both poles of the magnet, it showed south polarity.

From the powder of a piece of this hornblende rock 13·6 per cent. magnetic powder was extracted by means of the magnet; but the actual amount of magnetic iron-ore must, as in the previous instances, have been much smaller.

In order to ascertain the influence of distance upon the deflection of the magnetic needle, I placed a block, two feet and a half long, one foot broad, and one foot high, upon the floor of a room, in the same position, with regard to the dip and strike, as the rock of which it was a part, and ascertained the place at which the strongest north polarity of the rock deflected the magnetic needle 90° from the magnetic meridian. From this north pole I drew a parallel line to the magnetic meridian and determined, inch for inch, with the compass, the angle that the magnetic needle made with the magnetic meridian. At a distance of one inch, for instance, this angle amounted to $85^\circ 30'$; at a distance of twenty-four inches it amounted to $6^\circ 30'$. It followed that the square root of the tangent of the complementary angle varied as the distances of the compass needle from the above-mentioned north pole of the rock. Hence, at a distance of five feet from the block, the compass needle would be deflected 1° from its meridian,

* G. Rose.—Reise nach dem Ural, ii, 165.

† Gilbert's Annal. xxviii, 483.

and, consequently, that large masses of magnetic rock would exercise a considerable influence upon the magnetic needle. A repetition of these experiments, with an artificial magnet, which admitted of greater accuracy being attained, because the disturbances arising from the proximity of the poles in the block did not obtain, confirmed the previous observations. The differences between the square roots were far more constant in this case than in the former.

Magnetic polarity has been observed as a character of several basalt rocks. Thus the polarity of the basalt, upon which Dumbarton Castle is built, has been demonstrated beyond question by Anderson's observations,* Schulze † found, near the Nürburg in the Eifel, two rocks about six feet high, and about three feet apart, which presented magnetic polarity. Reuss ‡ observed magnetic polarity in two basalt rocks, in the central mountain range of Bohemia. One of these rocks, the "high Wostrai," manifests this polarity in so great a degree, that the magnetic needle is deflected, at its eastern base, 40° westward, and, at the summit, 90° westward. At the western base, the reverse deflection took place. The basalt constituting these rocks is very fine grained, and contains a very great number of extremely small augite crystals; but there was no recognizable trace of magnetic iron-ore, which is a proof that this mineral may be present in a rock without being recognizable mineralogically.

Zeune § describes the magnetic action of three basaltic cones in the Saxon Erzgebirge; the Pöhlberg, near Annaberg; the Scheibenberg, and Bärenstein hills. F. Reich || selected the Pöhlberg for magnetic observations, because it was isolated, and rose steep above the surrounding gneiss mountains. He made oscillation observations with the compass, at twenty-four points, all round the rock, at distances of from 200 to 300 yards, and determined the magnetic azimuth of each line from both terminal points.

He found that the magnetic polarity of this basalt rock did not exercise any influence, or at most a very slight influence, upon the direction of the magnetic needle, at any considerable distance. The strong magnetic polarity of this basalt is limited to a few points, irregularly situated in the rock; it varies at short distances,

* Buchanan.—Hist. Scotiæ, xx, 28.

† Schweigger's Journ. lii, 221.

‡ Ibid, liii, 236.

§ Ueber Basalt-polarität.—Berlin, 1809.

|| Poggend. Annal. lxxvii, 32.

and exercises, at a distance of four feet from the surface, only a proportionally slight action.

Zaddach * made very accurate observations of the magnetic polarity of the above-mentioned two basalt rocks near Nürnberg, and came to the conclusion that the magnetic iron-ore in the basalt was the chief source of the magnetic polarity, and that the other constituents, though in most instances somewhat magnetic, were so in a much less degree.

Numerous observations of the above-mentioned basalt, and many others, as well as trachyte rocks, show that the intensity of the magnetic polarity bears no definite proportion to the density of the rock, and, consequently, to the greater or less amount of magnetic iron-ore or hornblende; and, further, that when the surface of the rock is decomposed, and the magnetic iron-ore converted into hydrated peroxide of iron, the magnetic action of the rock is not weakened. He observed, that frequently those parts of the rocks were polar, which were traversed by numerous fissures and cracks, and which were at or near the surface, exposed to the influence of the atmosphere; while underneath the surface the polarity soon ceased to be manifested, and is not at all perceptible in basalt that is situated far below the surface of the earth.

In reference to those paradoxical phenomena, Zaddach mentions similar characters that had previously been observed. Thus J. H. Gmelin † states that at a magnetic rock, between Catharinenburg and Tobolsk, those parts of the magnetic iron-ore, which are exposed to the atmosphere, manifest the most decided magnetic force, while in those which are buried underground, it is much more feeble. Colonel Gibbs states that the iron-ore at Succasunny is magnetic only at the upper part, but not at the lower parts, and that it becomes magnetic only when it has been exposed for some time to the influence of the atmosphere. It is well known that the magnetic polarity of different specimens of pure magnetic iron-ore varies much in degree, and that some specimens are not at all polar. According to Zeune ‡ the magnetic polarity manifests itself in the highest basalt columns, at the Pöhlberg, more than at lower points. Zaddach and Förstemann observed the same fact at several basalt rocks in the Eifel.

* Beobachtungen über die magnetische Polarität des Basalt und trachytischen Gesteine. Bonn, 1851.

† Reise durch Sibirien, 1752, iv, 345.

‡ Loc. cit.

If all the magnetic iron-ore occurring in rocks, is a product of the decomposition of protosilicate of iron, as I shall subsequently have occasion to show it is, it becomes obvious that the rocks will become more magnetic, when, in proportion to the advance of the decomposition, more magnetic iron-ore has been formed. This consideration will, without difficulty, account for the production of polarity under the influence of the decomposing agents, and for the polarity being manifested to a greater degree when the rocks are much rent or fissured. When the other constituents of basalt, besides magnetic iron-ore, manifest polarity, this can only arise from the decomposition of the protosilicate of iron contained in them, although it may have proceeded to such an extent only, that the presence of magnetic iron-ore is imperceptible to the eye, and is indicated only by means of the magnet.

When the decomposition of basalt, and other magnetic rocks, has advanced so far, that the magnetic iron-ore, previously produced, is decomposed, its protoxide of iron being converted into peroxide by the same process of oxidation, the magnetic character of the mass will disappear.

Since, however, Plücker* has found that crystals of specular iron-ore, from Elba, manifest considerable polarity, and, since Zaddach has found this the case with almost all crystals of specular iron-ore that he has examined, there is the more reason for the conjecture, that the peroxide of iron, originating from magnetic iron-ore, remains polar for a long time. Moreover, the minutest trace of protoxide of iron in specular iron-ore, would, though not recognizable by chemical analysis, render it magnetic. It may, therefore, be understood, why, according to Zaddach's observation, a partial conversion of the magnetic iron-ore into hydrated peroxide of iron does not appear to reduce the magnetic action of the rock.

Magnetic characters were detected in granite by v. Trebra and Schröder† in 1785, at the "Schnarcher," two pyramidal granitic rocks in the Harz mountains. Wächter,‡ who determined the magnetic poles, found some other, perfectly isolated granite rocks, the Ilsenstein, near Ilsenberg, and the Hohneklappen, in the Harz mountains, which also manifested magnetic polarity. In all these rocks, the south pole was situated at the eastern side, and the north pole at the western side, but indifferent parts were much

* Poggend. Annal. lxxviii, 429.

† Gilbert's Annalen. der Physik, v, 376.

‡ Ibid.

more frequent than the active parts. Wächter remarks, that the granite of the Ilsenstein was yellowish, and not very compact, so that it was already somewhat decomposed. Further investigations of this subject were instituted by Hausmann, v. Zach, Friesleben, Lasius, and Jordan.* The last-named observer shows distinctly that the presence of magnetic iron-ore is the cause of the magnetic polarity of this granite. It occurs here and there in considerable amount, as small granules, seldom as large as a pea. At places where it occurs abundantly, the mica, which is generally scanty, disappears, sometimes entirely. Hausmann† observed that the polarity of the granite was proportionate to its compactness, and was less decided where the rock was weathered, and where, consequently, the magnetic iron-ore had been peroxidized.

Alex. v. Humboldt‡ describes a red clay-porphry, situated to the north of the volcano Pasto, near Quito, which was also magnetic, like the serpentine in the Fichtelgebirge.§ It presented very distinctly marked poles, and did not attract iron at all. It is worthy of remark that a clay-porphry, whose red colour indicates the preponderance of peroxide of iron, should manifest such decided magnetic characters.

Bouguer|| found similar magnetic rocks, scattered over the ground, between La Plata and Honda. In this district the deviation of the magnetic needle varied considerably. At distances of five or six yards apart, it sometimes differed as much as 30°.

Galbraith¶ found that the rock at Arthur's seat is magnetic. Jameson adds;** "independent of the disturbances produced by the proximity of the trapp in the Western Islands, there is upon the western coasts chiefly, a general irregularity in the magnetic deviation, which is undoubtedly produced by the joint influence of gigantic masses of trapp, or other rocks. It is sufficiently recognizable upon the sea, to limit considerably the utility of the compass in navigation between the islands."

Reich†† remarks, that it is very desirable, that numerous observations should be made in districts, where considerable variations

* Gilbert's *Annalen. der Physik*, xxvi 256.

† Ibid, p. 270.

‡ Ibid, xvi, 461.—It might be conjectured that the protosilicate of iron in mica had furnished the material for the formation of magnetic iron-ore.

§ See ante, p. 495.

|| Fig. de la terre. *Voy. au Perou*, p. 83.

¶ Edinb. new *Philos. Journ.* 1831, p. 287.

** Ibid, p. 285.

†† Loc. cit. p. 37.

in the deviation are noticed, and at places not far distant, so as to ascertain whether these variations are not limited to particular localities. That this is the case, would appear from Sabine's* observations of the inclination and intensity, at different parts of Scotland, which do not at all indicate disturbances effected by large mountains at considerable distances.

On the other hand, Hansteen† states, that large mountain ranges exercise a sensible influence upon the mean direction of the magnetic needle. This result is obtained from an extended series of observations, made by himself, as to the deviation and dip of the magnetic needle, and the magnetic force, during a journey through Sweden, and especially through the mountainous western part of Norway. However, this influence does not extend beyond a few miles, and does not upon the whole affect the distribution of magnetism over the earth.‡ He remarks that it would be very difficult to determine the true horizontal intensity of magnetism, in mountainous countries like the south-west coasts of Norway and Sweden, if by this term is understood that magnetic intensity which is solely attributable to the situation of the place, with regard to the magnetic axes of the earth, independent of the local magnetism of the neighbourhood.

Such disturbances are observed throughout the whole country round Christiana. According to Hansteen's observations of both the horizontal intensity, and the inclination, the existence of local magnetism—mountain magnetism—is indicated by an augmented horizontal intensity and smaller inclination, in the country more remote from Christiana.

The influence of coasts upon the magnetic needle was observed by Cook§ during his third voyage, in 1778, between the South Sea Islands, and in Nootka Sound; it was also observed by La Perouse,|| near Teneriffe. Fournet¶ infers from numerous observations of the intensity of magnetism, in Italy, and in the Alps, by Kreil, as well as from the determination of the terrestrial magnetic pole, by various expeditions to the antartic region, that there are local disturbances of unequal extent, or, in other words, that mountains exercise magnetic influence.

* Report on the sixth meeting of the British Assoc. for the advancement of Science, v, 97.

† Gilbert's Annalen. lxxv, 189.

‡ Poggend. Annal. iii, 225 and 386.

§ Gilbert's Annal. xxxv, 237.

|| Ibid, xxxii, 81.

¶ Annales de la Société d'Agriculture, Hist. Nat. et Arts Utiles de Lyon, 1848.

Forbes* also infers from his observations of the intensity of magnetism in different parts of Europe, that mountain ranges produce irregularities in the course of the magnetic curves.

A comparison of the undoubted effects of mountain magnetism at such distances as the above, with the results of Reich's observations,† leads to the conclusion, that these effects must be ascribed to the presence of masses of magnetic iron-ore, far exceeding in magnitude those in the basalt of the Pöhlberg.

Sweden and Norway are among the countries in which magnetic iron-ore chiefly occurs as beds and dykes of considerable extent, and consequently, it is not at all remarkable that its influence upon the magnetic needle should be manifested to such considerable distances.

Assuming that it is magnetic iron-ore alone, either as masses, or disseminated through rocks, to which the magnetic influences are to be ascribed, and in my opinion, this is quite unquestionable, it would seem, that magnetic observations, instituted with the same degree of care as those made by Reich, would be well adapted for the discovery of hidden beds of magnetic iron-ore. Such observations might, therefore, prove eminently serviceable to the iron industry. Certainly, it would be requisite first to ascertain whether mountain masses, containing only disseminated magnetic iron-ore, but extending over a considerable surface, would not produce as great an effect as beds of magnetic iron-ore. Sabine's observations do not appear to favour this. But, however this may be, the magnetic needle indicates the presence of magnetic iron-ore, where it cannot be recognized mineralogically, and demonstrates the very general distribution of this mineral.

Magnetic iron-ore dissolves completely in hydrochloric acid. When less acid is employed than would be requisite for perfect solution, the protoxide of iron is principally dissolved and brownish peroxide of iron remains.

Occurrence.—Magnetic iron-ore occurs partly, as an essential constituent of crystalline rocks—basalt, dolerite—and partly, as an accidental constituent of rocks. Thus in the granite at Hitteröe, in Norway, it is so abundant that it might almost be

* Phil. Mag. xi, 58, 366, and 370.

† See ante, p. 497.

included among the essential constituents of this rock.* It also occurs in gneiss and micaceous schist, very abundantly in serpentine, talcose and chloritic schist, hornblende rock, gabbro, hyperite, "schalstein" and in volcanic rocks, as at Monte Somma. It not unfrequently occurs in clay-slate, quartzite and granular limestone.† In some rocks it occurs as thick beds, and sometimes constitutes entire mountains.

It also occurs in dykes and drusy cavities. It has been found as loose sand at the Iserwiese in the Riesengebirge, in the Sieben-gebirge, upon the shores of the lake of Laach, and of other lakes and sea shores; also in the bed of rivers and brooks. In the Ural mountains it occurs in alluvial deposits, in great quantity, generally as small octahedrons, and for the most part, among the smaller particles, next to quartz the most abundantly.‡ Lastly it was found by Monticelli and Covelli,§ in the sand thrown out of Vesuvius in 1822.

The occurrence of magnetic iron-ore in many minerals, whose magnetic characters indicate its presence is worthy of remark. On the other hand various minerals occur imbedded in it.

Composition.

	I.	II.	III.	IV.	V.	VI.
Peroxide of iron	71·93	74·96	68·40	70·55	69·93	69·43
Protoxide of iron	28·07	25·04	30·88	29·45	30·07	30·57
	100·00	100·00	99·28	100·00	100·00	100·00

	VII.	VIII.	IX.	X.	XI.	XII.
Peroxide of iron....	75·87	70·14	69·40	71·07	67·56	70·21
Protoxide of iron	22·07	29·61	28·25	28·93	28·66	29·79
Protoxide of manganese....	2·06	....	....	....	....	....
Specular iron-ore ....	....	....	1·85	....	....	....
Iserine ....	....	0·25	....	....	3·31	....
	100·00	100·00	99·50	100·00	99·53	100·00

* Zachau.—Jahrbuch für Mineral, etc., 1855, p. 513.

† See ante, p. 192.

‡ G. Rose.—Reise nach dem Ural, ii, 476.

§ Der Vesuv.—German translation, p. 213.

	XIII.	XIV.	XV.	XVI.
Peroxide of iron	68·20	48·07	51·86	68·97
Protoxide of iron	14·29	39·16	40·27	31·03
Protoxide of manganese	17·51	....	....	....
Titanic acid ....	....	11·51	9·63	....
	100·00	98·74	101·76	100·00

	Analyzed by
I. Magnetic iron-ore from Norway	Berzelius.*
II. Crystallized magnetic iron-ore, from Schwarzenstein, in the Zillerthal	} v. Kobell.†
III. Crystallized magnetic iron-ore	
IV. Compact magnetic iron-ore, from Thorsäker in Sweden	} Fuchs.‡
V. Compact, granular, magnetic iron ore, from Arendal	
VI. Crystallized magnetic iron-ore. from Berggieshübel in Saxony	} Karsten.§
VII. Conchoidal magnetic iron-ore from Arendal	
	} v. Kobell.||
In this analysis an admixture of silica was deducted ; some of the protoxide of iron is replaced by protoxide of manganese.	
VIII. Octahedral magnetic iron-ore, from Danemora	} Karsten.¶
IX. Granular magnetic iron-ore, mixed with specular iron-ore, from Gellivara in Lapland	
X. Composition of the previous mineral, after deducting the specular iron-ore	} Karsten.¶
XI. Octahedral magnetic iron-ore, from the chloritic schist of the Tyrol	
XII. Composition of the previous mineral, after deducting the iserine	} Karsten.¶

* Schweigger's Journ. xv, 294.
† Ibid, lxii, 195.
‡ Journ. für prakt. Chemie, xvii, 170.
§ Archiv. für Mineral. etc., xvi, 17.
|| Schweigger's Journ. lxiv, 429.
¶ Loc. cit.

Analyzed by

- XIII. Earthy magnetic iron-ore, from the
 “Alte Birke” mine, near Siegen } Genth.*

This is the mean of three analyses, after deducting sand, etc. About one half of the protoxide of iron is replaced by protoxide of manganese.

- XIV. Scoriaceous magnetic iron-ore, from
 the basalt near Unkel on the Rhine } Rammelsberg.†

- XV. Magnetic iron-ore from the decom-
 posed basalt of the Virneberg, } R. Rhodius.‡
 near Rheinbreitenbach

The minerals represented by the last two analyses, may be regarded as magnetic iron-ore with a portion of the peroxide of iron, replaced by oxide of titanium.

XVI. Theoretical composition of magnetic iron-ore, assuming that it is a compound of peroxide and protoxide of iron, in atomic proportions.

Comparison of the theoretical composition with the results of analysis, shows that the peroxide of iron is generally rather more than calculation requires. But, nevertheless, I am of opinion that this mineral is a definite compound, and consider that the opposite view, held by some mineralogists is erroneous, for the variation in the proportion of the two oxides is in all probability owing to the conversion of the magnetic iron-ore into specular iron-ore and brown iron-ore, which, as I shall subsequently have occasion to show, takes place very frequently.

When this alteration is merely incipient, and is not indicated by any apparent alteration of the external characters, an increase in the amount of peroxide of iron would still be indicated by chemical analysis. Moreover, the surplus peroxide of iron, may frequently be only apparent, and the result of inaccurate analysis.

Alteration of magnetic iron-ore, accompanied with increase in the proportion of protoxide of iron, has not yet been observed; and, in no instance, has the amount of protoxide of iron been found to exceed that required by calculation; consequently it would appear, that the peroxide of iron, in magnetic iron-ore, is not susceptible of reduction, by organic substance for instance.

Formation.—I consider it to be necessary to bring forward all the evidence of the formation of magnetic iron-ore in the wet

* Ann. der Chem. u. Pharm. lxvi, 277.

† Poggend. Annal. liii, 129.

‡ Ann. der Chem. u. Pharm. lxiii, 218.

way, although without denying the possibility of its being formed by fusion also. This is the more necessary since most geologists have been, and still are of opinion, that the latter is the only way in which magnetic iron-ore is formed.

At Vesuvius, crystals of magnetic iron-ore, generally very small, occur mixed with glassy felspar and nepheline,* and associated with hornstone in drusy cavities of ejected masses of lava. Blum has a specimen of this lava in which, besides magnetic iron-ore and hornstone associated together in the pores, there is a small octahedron of magnetic iron-ore, seated upon the hornstone, and partly surrounded by it. This magnetic iron-ore is unquestionably more recent than the hornstone, and as this zeolite contains 15 per cent. water, it is impossible that the magnetic iron-ore, seated upon it, can have been formed by fusion.

The assumption that the water of the harmotome has been retained under the influence of considerable pressure, would not remove the difficulty, for however great may have been the pressure exerted within the volcano, the lava must, during the long period of cooling, after having been thrown out, have experienced only the ordinary atmospheric pressure, and consequently, the water, that might previously have been retained, would then escape.

Harmotome is formed in lava, in the same manner as it is formed in drusy cavities of amygdaloid rocks; and this takes place long after the eruption of the lava. Nor does it appear possible to ascribe any other mode of origin to the magnetic iron-ore. Augite, the material for its formation, is not deficient, either in lava or in volcanic bombs. Moreover, the drusy cavities of lava sometimes contain granular masses of magnetic iron-ore, mixed with small particles of mica, and with delicate mica crystals.

Blum has a specimen of granular magnetic iron-ore, mixed with minute quartz granules, in which there is a nucleus of *spirifer speciosus*, the magnetic iron-ore is mixed with iron pyrites and traversed by veins of bitter-spar. In the drusy cavities there are very fine crystals of quartz, upon which are situated bitter-spar and iron-spar. The presence of fossils in minerals formed by fusion is impossible, and this specimen altogether furnishes strong evidence of the formation of magnetic iron-ore in

* In the lava at the Capo di bove it is not unfrequent to find in the same cavity crystals of calc-spar, of different zeolites and magnetic iron-ore.—Eichwald. —Nouveaux Mém. de la Soc. imp. des Natural. de Moscou, ix, 259.

the wet way. Thus the very frequent occurrence of magnetic iron-ore in drusy cavities, even those in compact magnetic iron-ore, can only be ascribed to deposition from water, although the solubility of magnetic oxide of iron may not have been demonstrated.

All minerals that contain any considerable amount of protoxide and peroxide of iron, will furnish material for the formation of magnetic iron-ore. If these oxides should exist in the minerals, in the same proportion as in magnetic iron-ore, the whole amount may be eliminated as magnetic iron-ore. If protoxide of iron only is present, the formation of magnetic iron-ore presupposes the partial peroxidation of the iron. If peroxide of iron only is present there would be a partial reduction. There are innumerable phenomena which prove that such processes of reduction or oxidation take place in minerals.

However, it is not very probable that magnetic oxide of iron is eliminated from persilicate of iron, which has been partially reduced by means of organic substance; for it is certainly very rare that minerals containing only these silicates are primitive. On the contrary, it would appear, that the protosilicate of iron in minerals, gradually passes into persilicate. But, it is certain that elimination of magnetic oxide of iron would take place more readily during this transition, than at the last stage of the alteration, when the persilicate of iron would require to be reduced again to the state of protosilicate.

In unaltered compound silicates, such, for instance, as garnet, augite, and hornblende, the peroxide of iron can only be combined with silica. When magnetic iron ore is produced by the alteration of such minerals, as in the garnet* and basaltic hornblende;† this must be accompanied by elimination of silica. It would be very difficult to ascertain, whether or not these minerals contain uncombined silica, when they act upon the magnetic needle; but I shall subsequently have occasion to show that magnetic iron-ore and quartz not unfrequently occur together in rocks. The conversion of garnet into magnetic iron-ore and serpentine,‡ shows that the silica eliminated may also be consumed in the production of other products of decomposition.

The separation of peroxide of iron, or rather of basic persulphate of iron, during the oxidation of protosulphate of iron, is analogous to the elimination of a portion of the base, as peroxide

* See ante, pp. 285 and 292.

† Zaddach.—Loc. cit. p. 60.

‡ See ante, p. 291.

of iron, from protosilicate, during its peroxidation. The separation of hydrated peroxide of iron, from compound silicates, containing protosilicate of iron, is a very general phenomenon, when these minerals are subjected to oxidizing influences. However, it does not account for the production of magnetic iron-ore; but shows that there must be special conditions, under which the elimination of a compound of peroxide of iron with protoxide of iron takes place, instead of the elimination of a compound of peroxide of iron with water.

The very frequent occurrence of magnetic iron-ore proves that the oxides of iron have a strong tendency to combine in definite proportions.* The compound may be regarded as saline, with protoxide of iron as the base. Consequently, when, by peroxidation of protosilicate of iron, peroxide is formed, and the chemical affinity of the protoxide and silica, counterbalanced, the conditions for the combination of the two oxides would be most favorable. But if, at the same time, silica is not eliminated as quartz, it must be inferred that, by entering into combination, either with the residual protosilicate of iron, or with the other silicates, it forms silicates with larger amount of silica.

As silicates with the largest amount of silica occur in the most frequent minerals, such as felspar, it may be inferred that there is a greater tendency to the formation of silicates of this kind, than there is to the formation of silicates with the smaller amounts of silica.†

Assuming that in the production of magnetic iron-ore from minerals with small amounts of silica, such as garnet, augite, and hornblende, a portion of the silica is liberated, this tendency to the production of minerals with large amounts of silica would be favored. According to this view, the production of magnetic iron-ore, from protosilicates of iron, would be the result of the strong chemical affinity between protoxide of iron and oxygen together with the tendency to the formation of silicates with large amounts of silica.

* This appears also in the fact that peroxide of iron determines the decomposition of water by metallic iron with evolution of hydrogen.—H. Rose.—Poggend. Annal. lxxxiii. 135.

A compound of peroxide and protoxide of iron is also formed when water-vapour is decomposed by ignited iron wire.

† Suppositious chemical processes, relating to mineral alteration and production, gain probability when they can be proved analogous to experimental processes. The tendency of silica to form acid compounds would have its analogy in the tendency of tartaric acid to form acid salts. Tartaric acid abstracts potash even from sulphate of potash, and the weakest acids are capable of abstracting sufficient base from tartrate of potash, to form acid tartrate.

The conversion of augite into hornblende and garnet, as well as into hornblende and magnetic iron-ore has been already referred to.* These alterations have taken place to an immense extent, near Arendal. Thus Weibye† states, that, at the Thorbjörnsbo mine, the iron-ore is intimately mixed with the granular red garnet, and augite or hornblende, and, that detached fragments of this mixture are sometimes imbedded in magnetic iron-ore, sometimes blended with it, and that it also surrounds masses of magnetic iron-ore.

It generally happens that the masses of ore occurring in this mine, are sharply separated from the adjoining rocks, consisting, partly, of syenite, and partly of granite, with several minerals such, as augite, garnet, mica, coccolite, etc., which generally surround the iron-ore as a crust, but sometimes extend into the rock or pass gradually into it.

The association of augite, hornblende, garnet, serpentine, with magnetic iron-ore, at Orpus and Presnitz, in Bohemia; and the association of garnet and magnetic iron-ore with the hornblende rock, which, in that country traverses the slate rocks,‡ also indicate alterations similar to that at Arendal.

There are also other places where phenomena present themselves, which indicate the conversion of augite into magnetic iron-ore. Among these the Ural, with its mountains of magnetic iron-ore, claims the first notice.

Near Nischne-Tagilsk, a ridge, consisting, for the most part, of pure magnetic iron-ore, 300 fathoms long, 250 broad, and 41 fathoms high, rises above the level of the Wigsokaja-Gora. The granular varieties are sometimes traversed by fissures or cavities, upon the inner sides of which are small, sharp octahedrons. This enormous mass of ore is imbedded in clay of a white, yellow, or brown colour, and from which it is distinctly separated. But at the north side there is a wedge shaped mass of rock without ore extending to the summit, and at the east side this rock is separated from the iron-ore by a layer of clay only one foot thick. This rock is probably augitic porphyry containing much labradorite and some few quartz granules.§

The Blagodatskaya, near Kuschwinsk, is an isolated range, separated by two hollows into three parts. The whole declivity towards Kuschwinsk consists of a very fine augitic porphyry, the

* See ante, p. 330.

† Jahrb. für Mineral. etc., 1847, p. 699.

‡ Zippe.—Abhandl. der böhm. Gesellschaft der Wissen, Folge 5, iv.

§ G. Rose.—Reise, etc., i, 310.

principal mass of which is magnetic. It contains augite crystals of a grass-green colour, and at some places near the summit they are surrounded with an envelope of uralite. White patches are also recognizable in the mass, which probably consist of labradorite. At the surface of the rock they appear converted into white porcelain earth. These substances are washed away by water, and the augite and uralite crystals, which resist alteration better, project beyond the surface of the rock. Sometimes the augitic porphyry of Blagodat is amygdaloid, and presents cavities filled with calc-spar. The augitic porphyry at the western declivity does not yet contain magnetic iron-ore, but it begins to appear at the summit, and then occurs, in great abundance, as large masses of great purity, though here and there, alternating with other masses, so that, it is obvious, magnetic iron-ore and other constituents of the rock were formed simultaneously. The magnetic iron-ore sometimes contains drusy cavities with octahedral crystals of magnetic iron-ore. Iron pyrites also occurs in drusy cavities, together with magnetic iron-ore, and sometimes imbedded in it. Calc-spar is mixed with the iron-ore, for the most part only in small masses, but at the southern side it is said to traverse the ore, frequently as layers, several feet thick. Analcime occurs blended with magnetic iron-ore, and imbedded in it.*

Near Nischne-Turinsk there is a mountain called Katschkanar, more than five wersts long, from which magnetic iron-ore rises as detached peaks. The rock is probably augitic porphyry like that at Blagodat; one of the specimens obtained thence appears to be a granular mixture of augite and magnetic iron-ore; another consists of very coarse granules of augite with a little magnetic iron-ore disseminated through the mass.†

With the exception of the uralite originating from the alteration of the augite crystals at the Blagodat, no mention is made of the association of augite, hornblende, and garnet, as observed at Arendal.

In the Erzgebirge, round Schwarzenberg, magnetic iron-ore occurs as narrow layers, mixed with granular limestone, and very frequently associated with garnet.‡ In the deposits of ore in the green-stone rocks of that district, it is rarely wanting, and is associated with hornblende, diopside, sahlite, garnet, quartz, etc.

* G. Rose.—Reise, etc., 1847, p. 342.

† Ibid, p. 379.

‡ Freiesleben.—Geognost. Arbeiten. v, 42.

Credner* states, that in the Thuringian forests, magnetic iron ore is always associated with the hyperite—hypersthene rock—specular iron-ore also occurs frequently with it, and the rock does not contain any quartz. The similarity between hypersthene and augite admits of the conjecture, that the magnetic iron ore, and the specular iron-ore are, in this instance, products of the decomposition of the hypersthene.

The hornblende rock in the Thuringian forest, is also associated with granular magnetic iron-ore, which appears, sometimes, entirely to replace the hornblende. The magnetic iron-ore is mixed with thin parallel layers of quartz.

The remarks made with regard to hypersthene, are also applicable to diallage. The frequent presence of magnetic iron-ore in gabbro also indicates that it originates from the decomposition of diallage. Minute particles of magnetic iron-ore are sometimes mixed with diallage.†

The above-mentioned phenomena demonstrate that magnetic iron-ore may originate from augite, and probably also from minerals related to it. Then comes the question, whether this magnetic oxide of iron can be eliminated in any other than the wet way, and whether it is possible to entertain the opinion that it is eliminated by igneous action.

The oxides of iron are strong bases, which have a great chemical affinity for silica, and enter into combination with it readily at a moderate heat. This is illustrated in metallurgical operations; thus, in copper smelting, siliceous substances are added to the ores for the purpose of obtaining the protoxide of iron in combination with the silica as an easily fusible slag. It is also illustrated in the welding of iron, in which operation the white hot iron is covered with fine sand, in order that the oxide of iron formed at the surface may form with it a fusible slag that will be pressed out by the hammering, so that the pure metallic surfaces may come in contact.

Since then, magnetic oxide of iron combines with silica so readily under the influence of heat, it is impossible to suppose, that, during the solidification and cooling of a mass of melted rock, magnetic iron-ore and quartz would be eliminated. Consequently, where magnetic iron-ore occurs in a granite rock, or in any rock containing quartz, it cannot have been separated from a melted mass. Thus, for instance, at Arendal, the magnetic iron-ore frequently ramifies into the adjoining syenitic or granitic rocks,

* Jahrb. für Mineral. etc., 1843, p. 272.

† G. Rose.—Reise, etc., ii, 165.

and this is an instance in which it cannot have been formed by fusion. Nor could it have been produced by a plutonic metamorphism of the gneiss. Therefore, if syenite and granite are really products of igneous action, magnetic iron-ore cannot have been separated during their solidification.

The association of magnetic iron-ore and quartz is by no means a merely local phenomenon. At Ulefoss, in Norway, both minerals occur together in a bed of magnetic iron-ore. Quartz crystals often occur in the midst of magnetic iron-ore. In the beds of magnetic iron-ore in Sweden, Brazil and Paraguay, quartz occurs very abundantly. Near Slatoust, magnetic iron-ore occurs in a coarse grained granite, together with quartz and hornblende crystals, and in such quantity, as to constitute a rich iron-ore.* At Fahlun, it occurs associated with copper-pyrites, iron-pyrites, galena, and blende in a quartzose matrix.† In the Bredgange mine, near Kongsberg, it occurs, mixed with quartz, hornblende, garnet, and calc-spar.‡ Several of the rivers and streams in the Erzegebirge—the great Zscharde, the Elster, the Weiseritz, etc.—bring down quartz, magnetic iron-ore, and iserine, and mixtures of these substances occur in the bed of the Elbe, so that it is probable that quartz and magnetic iron-ore are associated in these mountains. The association of these minerals in alluvial deposits in the Ural, has already been mentioned.§

If it should be admitted, by those who adhere to the plutonic doctrines, that the quartz, associated with magnetic iron-ore, has been formed in the wet way, it would still be impossible to maintain the opinion that the magnetic iron-ore was formed by fusion. For if quartz were surrounded by melted magnetic iron-ore, the same result would be produced that is observed in the welding of iron, and that indeed more readily, for, according to this view, the quartz crystals would have been brought in contact with melted magnetic oxide of iron.

Weibye states that in many of the mines at Arendal, the imbedded masses are less frequent in proportion to the depth of the working. This accounts for the less frequent occurrence of the numerous minerals, that are otherwise so abundant, but which occur almost solely in these masses.

This fact is precisely the reverse of what might be expected, if these masses were produced by igneous action, and is entirely

* G. Rose.—Reise, etc., ii, 139.

+ Daubrée.—Skandnaviens Erzlagerstatten, p. 30.

‡ Scheerer.—Jahrb. für Mineral. etc., 1843, 635.

§ See ante, p. 503.

consistent with the opinion that they have been produced by the action of surface water; for near the surface the alterations caused by water would be more obvious, owing to the greater prevalence of the requisite conditions, while the effects produced by heat, would be very small, owing to the remoteness of the source at the interior of the earth.

The question then presents itself; are all the beds of magnetic iron-ore, in Norway, products of the decomposition of augite? This would be more susceptible of determination, if it were practicable to estimate the quantities of the magnetic iron-ore, the carbonate of lime, the carbonate and silicate of magnesia, and the silica, which may be products of the decomposition and to ascertain how far they represent the constituents of the decomposed augite. The actual occurrence of these products of decomposition would naturally suggest the probability that the magnetic iron-ore with which they are associated, has originated in this way. In the magnetic iron-ore mines of Norway, calc-spar occurs chiefly; but bitter-spar occurs sometimes, as in the island of Lango. Of the minerals containing silicate of magnesia, chlorite occurs, here and there, in all the mines of Arendal, serpentine also occurs, and talc, somewhat abundantly. The serpentine occurs, in part, as small masses, imbedded in magnetic iron-ore, or in the mixture of various minerals accompanying it; in part, as small fragments in the adjoining rock; and in part, as beds between the magnetic iron-ore, and coccolite. Quartz occurs very frequently in separate masses varying in size, both in and around the mines.* Since, therefore, the products of the decomposition of augite, other than magnetic iron-ore, occur in the mines of Norway, no question can be raised as to the possibility of the magnetic iron-ore having originated in this way.

At the magnetic mountain Wissokaja Gora, clay occurs, which is, undoubtedly, a product of the decomposition of the felspathic mass—labradorite—of the augitic porphyry, and, in part also, of augite. The unproductive rock is, according to Hermann's description, a disintegrated porphyry, consisting of jasper with felspar and isolated granules of quartz. In this instance, therefore, the silica, eliminated in the decomposition of the porphyry, presents itself.

At the Blagodat, calc-spar occurs in drusy cavities, mixed with magnetic iron-ore; and it is also stated to traverse the ore

* Weibye.—Loc. cit.

as layers of some thickness. This carbonate of lime is a product of the decomposition of the silicate of lime in augite and labrador, by means of water containing carbonic acid. In the analcime from the Blagodatskaya, containing, according to Henry, 11·86 per cent. soda, and 0·55 per cent. potash, the alkalies of the decomposed labrador present themselves.

When the magnetic iron-ore occurs pure, as at Wissokaja Gora, the volume, as well as the mass, of the original augitic porphyry, must have been very considerably diminished; for the specific gravity of the magnetic iron-ore is nearly double as great as that of the rock. In one of the mines at Arendal, a space of some hundred feet in length and at least fifty feet broad, was found to be entirely filled with magnetic iron-ore.*

The augite which contains the largest amount of iron is hedenbergite, in which there is 26 per cent. protoxide of iron. This quantity, when converted into magnetic iron-ore, would amount to 28 per cent.; so that in the production of magnetic iron-ore from such augite, the substance eliminated would amount to 72 per cent. If the augitic porphyry consisted of equal parts of augite and labrador, the magnetic iron-ore produced, would amount to only 14 per cent. of the mass, and only 8 per cent. of the volume of the rock. If the augitic porphyry retained its original volume, the magnetic iron-ore originating from it would have been extremely porous, or traversed by numerous fissures and cavities. However, this is not found to be the case; and it is only in those cases where the whole of the products of the alteration of the augitic porphyry remain in the space occupied by it, that the mass would not be reduced, but somewhat increased, owing to the introduction of carbonic acid and the peroxidation of the iron.

It rests with those who adhere to the plutonic doctrine, to show whether the opinion, that magnetic iron-ore had an eruptive origin, simultaneous with that of the augitic porphyry, is better adapted to account for the mineralogical features of its occurrence, than the decomposition of augitic porphyry in the wet way. It would also devolve upon them to account for the situation of the magnetic iron-ore, at Wissokaja Gora, in clay; for this clay being interposed between the unproductive rock and the magnetic iron-ore; and for the occurrence of magnetic iron-ore blended with a zeolite.

It is, however, not only the presence of this zeolite that indi-

* Scheerer.—*Jahrb. für Mineral, etc.*, 1843, p. 631.

cates the prevalence of alteration in the wet way; the brown iron-ore that occurs towards the sides, and at the surface of the magnetic iron-ore, both mixed with it, and almost pure in fissures, unmistakably testifies to the action of water. This is also true of the iron pyrites mixed with the magnetic iron-ore.

The very frequent occurrence of magnetic iron-ore in serpentine, is particularly characteristic, for the same minerals—garnet, augite, and hornblende—that are convertible into serpentine, are also capable of yielding magnetic iron-ore by their decomposition.

The greenish-grey slate at Deville, and the grey slate at Rimogne, both belonging to the silurian group, contain magnetic iron-ore; in the former one it is crystallized.* The occurrence of magnetic iron-ore, in clay slate, either disseminated, or upon dykes, is not at all unfrequent. In the “Schalstein,” near Odersback, in Nassau, beds of magnetic iron-ore occur, which sometimes contain steatite.†

Since magnetic iron ore may originate in the decomposition of augitic porphyry, it is possible that basalt, which consists, for the most part, of the same minerals—augite, and labradorite—may, by decomposition, yield magnetic iron-ore. It has already‡ been shown that is actually the case.

Acids extract from basalt a certain amount of protoxide and peroxide of iron, which several chemists have held to represent magnetic iron-ore, and have hence estimated the amount of this mineral in basalt at, from 2 to 17 per cent. But Rammelsberg§ points out, in objection to this inference, that olivine, which is such an abundant constituent of basalt, is decomposed by hydrochloric acid; and, therefore, the amount of magnetic iron-ore would be estimated too high, unless the iron corresponding to the olivine present were deducted.

Magnetic iron-ore occurs in basalt, as, for instance, near Unkel, on the Rhine, both as minute particles, and as masses more than an inch in diameter. It generally appears as roundish masses, with fine conchoidal fracture. At this place, rent fragments of magnetic iron-ore are met with between adjoining basalt columns; and Nöggerath observed,|| that very often the detached portions of these masses, through which the divisional planes of the basalt pass, are not at the same level, but that one is several inches

* Sauvage.—Annal. des Mines, Sér 4, vii, 411.

† F. Sandberger.—Uebersicht der Geol., Verhält. des Herzog. Nassau, p. 35.

‡ See ante p. 498, et seq.

§ Handwörterbuch, etc., p. 77.

|| Der Bergschlupf an den Unkeler Basalt-brüchen, p. 11.

adhered to them so firmly, that they were rent, rather than displaced. But if it is assumed that basalt has been produced by igneous action, the opinion that the magnetic iron-ore has been produced subsequently to the basalt, must be given up.

If it were assumed that the masses of magnetic iron-ore were the contents of drusy cavities, it is obvious that the infiltration must have taken place prior to the columnar partition. Since, moreover, the basalt at Unkel, contains mesotype, arragonite, and a steatitic mineral, filling cavities from one to three inches in diameter, it follows that these minerals, which are products of infiltration, would appear divided and their parts attached to adjoining columns of basalt, if they had existed prior to the columnar partition. However, such a condition has not, in any instance, been observed, and these products of infiltration have certainly been formed long after the basalt, however that may have originated.*

As the idea of the igneous origin of rocks can only be derived from the observation of the masses erupted from volcanoes, it is necessary, in order to form an opinion of the possibility of magnetic iron-ore being produced by igneous action, to ascertain whether it occurs in these volcanic masses, and if so, under what conditions.

The presence of magnetic iron-ore in sand, thrown out of Vesuvius in 1822, and soon afterwards examined by Monticelli and Covelli,† does not furnish any evidence of the production of this mineral by igneous action; for this sand is nothing more than the débris of rocks, and though thrown out of a crater, does not necessarily originate from volcanic rocks. This is also the case with the magnetic iron-ore so frequently occurring in the beds of rivers and streams, and upon the shores of lakes and seas, with regard to which Cordier has instituted observations.‡ Moreover, Rammelsberg§ states that this magnetic iron-ore is mixed with iserine in varying proportion. This mixture originates either from sand, that was thrown out of a volcano, or from rocks, such as basalt, containing magnetic iron-ore as a constituent.

Even the octahedrons of magnetic iron-ore, half an inch in

* In the lateral faces of the basaltic columns from this place, small cavities are sometimes found filled with a zeolite—chabasite. It is not known what relation such masses of zeolite bear to the face of the adjoining basalt column, although such a knowledge would probably be very important in reference to the opinion entertained as to the genesis of basaltic columns.

† *Der Vesuv.*, etc.,—German Translation, p. 187.

‡ *Journ. des Mines* xxi, p. 249.

§ *Handwörterbuch*, p. 219.

diameter, found by Monticelli and Còvelli,* among the substances thrown out of Vesuvius in October 1822, in nodular and melted masses, might probably have existed at the interior of the volcano. At least, it cannot be assumed that this mineral would have been separated as such large crystals subsequent to the ejection of the masses from the crater; but it is much more probable that these crystals were pre-existent in rocks. As magnetic iron-ore is much less fusible than a basaltic matrix, it is probable that the heat in the volcano melted the mass of the rock, while the magnetic iron-ore remained imbedded in it unaltered. The few black specks of magnetic iron-ore in the lava poured out during the same eruption, may have the same origin.

However, in the case of an amygdaloid lava, of the same date, containing in its cavities very small, brilliant octahedrons of magnetic iron-ore, it is uncertain whether they were pre-existent, or whether they were formed during solidification of the mass.

The very frequent occurrence of magnetic iron-ore and iserine in the lava of more remote eruptions, as, for example, in the lava of the Capo di Bove, near Rome;† in the lava at Sorrento,‡ and several other places,§ does not favour the opinion that the magnetic iron-ore has been formed during the solidification of the mass; and this is more particularly the case since the above-mentioned association of magnetic iron-ore with hornstone proves the possibility of its being formed in the wet way.

There is no chemical evidence that can be brought forward against the opinion, that magnetic iron-ore is separated from rocks both in the wet way and by igneous action; for, on the one hand, a compound analogous to magnetic iron-ore may be prepared in the wet way,|| although the process by which it is produced cannot be supposed to take place in rocks; and, on the other hand, in the roasting of spathic iron-ore, perfectly regular octahedrons of magnetic iron-ore are sometimes formed, although, only when the mass melts.

Magnetic iron-ore with the form of iron-spar,—This is the only known case of the conversion of an iron-ore into magnetic iron-ore. Haidinger¶ states that some kinds of brown iron-ochre are mixed with magnetic iron-ore, which is recognizable at the interior, as

* Loc. cit., p. 213.

† Breislak.—Geologie, iii, 260.

‡ Breislak.—Reise durch Campanien, German translation, i, 154.

§ Breislak.—Geologie iii, 433.

|| Berzelius.—Jahrbuch der Chemie, 5te Ed. ii, 710.

¶ Abhandlungen der böhm. Gesell. der Wiss, Folge 5, iv.

isolated specks. This magnetic iron-ore has, probably, been formed by the partial oxidation of the carbonate of iron, in the wet way; and is an intermediate product of the conversion of the iron-spar into hydrated peroxide, which is accompanied by elimination of carbonic acid. Special conditions must have prevented the introduction of water.

Blum* describes a nodular specimen from the burning brown-coal at Carlsbad. It consists of earthy magnetic iron-ore, imbedded in burnt clay. At several parts of the former are a number of small crystals with the form of iron-spar, and containing within, a fine dark-bluish powder, that is slightly attracted by the magnet, and consists of pure, earthy, magnetic iron-ore. The substance that has undergone this alteration was evidently argillaceous sphærosiderite.

Pusch† refers to the occurrence of magnetic iron-ore, in the brown-coal at Töplitz, and originating from red hematite, by the action of burning brown-coal.

The above-mentioned‡ formation of magnetic iron-ore during the roasting of spathic iron-ore, shows that it may also be formed in rocks under these conditions. It is evident that the formation of magnetic iron-ore from carbonate of iron, by the action of melted basalt, which is assumed by some mineralogists, can have taken place only if a portion of the protoxide of iron was peroxidized simultaneously; and it is difficult to perceive how this should have taken place, as the access of air would have been prevented.

It is worthy of notice, that metallic iron may be converted into magnetic iron-ore, in the wet-way. Becquerel§ found, for instance, in the foundations of an old castle, iron bars almost entirely converted into hydrated peroxide of iron, magnetic iron-ore, and peroxide of iron. Both the latter substances were distinctly crystallized. Of course, such alterations cannot be supposed to take place in rocks, because metallic iron is of very rare occurrence.

Peroxide of iron, with the form of magnetic iron-ore.—This alteration has been observed in crystals, as well as in small particles of ore, and large masses. It is often so complete, that the altered mass had all the characters of specular iron-ore, except the form.

* Nachtrag, p. 100.

† Zeitschrift für Mineral, von Leonhard, 1826, p. 533.

‡ See ante p. 518.

§ L'Institut, 1843, No. 522.

Blum* mentions several localities in which octahedral peroxide of iron occurs, which has all the external characters of magnetic iron-ore, but gives a decided cherry-red streak. G. Rose† found these pseudomorphs in the serpentine at Kalinowkoi, near Beresowsk. These altered crystals have only a slight action upon the magnetic needle, sometimes none at all. Another specimen, consisting of chloritic schist, from Goyabeiras, in Brazil, contains a number of octahedrons of magnetic iron-ore; those which are situated at the weathered surface of the rock are converted into peroxide, while the others within the mass, where the oxidizing influence has not extended, appear quite unaltered. The same phenomenon presents itself in a talcose schist from Serra de Ouro Preto. These altered magnetic iron-ore octahedrons are also associated with magnetic iron-ore and hornblende, near Krageroe.‡ In the serpentine at Kalinowkoi, there is also a great number of small octahedrons of magnetic iron-ore, partially converted into red peroxide, and possessing little coherence.§

Glocker|| describes similar pseudomorphs, occurring in the granite near Schönberg, in Moravia, which present the laminae structure of specular iron-ore very distinctly. This pseudomorph is, therefore, quite analogous to that of hornblende with the form of augite,¶ and furnishes another illustration of the fact, that a perfectly crystalline mineral may present the form of another mineral, and still possess its own peculiar structure. But there must be in this case, a close relation between the chemical composition of the two minerals, as is the case with hornblende and augite, as well as in the case of specular iron-ore and magnetic iron-ore.

Glocker also describes granular magnetic iron-ore, occurring in Moravia, which is, for the most part, quite fresh and lustrous, and gives a black streak, but at some places gives a dirty cherry-red streak, though it does not present any external signs of alteration. Here again there has been a conversion into specular iron-ore. In another iron-ore, consisting of an intimate mixture of compact specular iron-ore, and compact magnetic iron-ore, a very gradual transition is recognizable from the colour. Glocker is, however,

* Die Pseudomorphosen, p. 32.

† Reise nach dem Ural, i, 234.

‡ Weibye.—Archiv für Mineral. etc., xxii, 517.

§ G. Rose.—Reise, etc., ii., 234.

|| Poggend. Annal. xvi, 264.

¶ See ante, p. 314.

of opinion, that the association of the two minerals does not always admit of the inference, that this conversion has taken place. Magnetic iron-ore occurs imbedded in specular iron-ore, and the reverse, and with slight variation of conditions, peroxide of iron may have been formed, together with magnetic oxide of iron.

The conversion of magnetic iron-ore into red hematite, appears rarely to take place. Glocker, however, observed, in a pale green talcose schist at Lettowitz, blood-red patches round imbedded magnetic iron-ore. These patches are either compact red hematite, or limestone highly impregnated with it, and are probably produced by the partial alteration of magnetic iron-ore.

For the conversion of magnetic iron-ore into peroxide of iron 3.44 per cent. oxygen must be introduced; so that the weight of the magnetic iron-ore would be increased to that amount; and as the average specific gravity of magnetic iron-ore and of peroxide of iron, is, in both cases, 5.05, the volume of the magnetic iron-ore is increased, by its conversion into peroxide of iron, in the same proportion as the actual weight. However, Breithaupt* found the specific gravity of three specimens of martite, was between 4.809 and 4.832, which is lower than the minimum specific gravity of magnetic iron-ore. Consequently, assuming that the specific gravity of the original magnetic iron-ore was 5.05 there must have been an increase of volume, in the production of these minerals, to the extent of 8.62 per cent. at least. Another specimen of iron-ore,† described by Breithaupt, and which is, according to Blum, altered magnetic iron-ore, has very nearly the same specific gravity as the original mineral.

Conversion of magnetic iron-ore into brown iron-ore.—Both minerals frequently occur in the same bed; sometimes distinctly separated, but more frequently perhaps, so intimately mixed, that the limits cannot be recognized. Thus, for instance, Glocker‡ describes an instance in Moravia, where the masses of perfectly fresh, granular, magnetic iron-ore, are surrounded by iron-ochre. At several places the magnetic iron-ore has entirely disappeared and there remains only a soft, impure, argillaceous brown iron-ore, which is a product of the alteration of the particles of magnetic iron-ore mixed with the clay-slate. Here the conversion of magnetic iron-ore into hydrated peroxide is on a large scale; for the brown iron-ore constitutes a thick bed.

* Schweigger's Journ. liv, 158.

† Loc. cit., p. 157.

‡ Loc. cit.

the presence of a larger amount of magnetic iron-ore, arising, perhaps, from alteration of the chrome iron-ore. G. Rose* also found chrome iron-ore associated with magnetic iron-ore, in all the varieties of serpentine of the Auschkul lake.

Displacement of magnetic iron-ore by other minerals.—There is only one instance of this kind, in which the displacing mineral is chlorite.†

* Reise nach dem Ural, ii, 165.

† See ante, p. 409.

THE END.

